Technical Report CERC-95-11
August 1995

US Army Corps of Engineers
Waterways Experiment Station

Camp Ellis Beach, Saco Bay, Maine, Model Study of Beach Erosion

Coastal Model Investigation

by Robert R. Bottin, Jr., Marvin G. Mize, Zeki Demirbilek

Approved For Public Release; Distribution Is Unlimited

Prepared for U.S. Army Engineer Division, New England

Technical Report CERC-95-11
August 1995

Camp Ellis Beach, Saco Bay, Maine, Model Study of Beach Erosion

Coastal Model Investigation

by Robert R. Bottin, Jr., Marvin G. Mize, Zeki Demirbilek

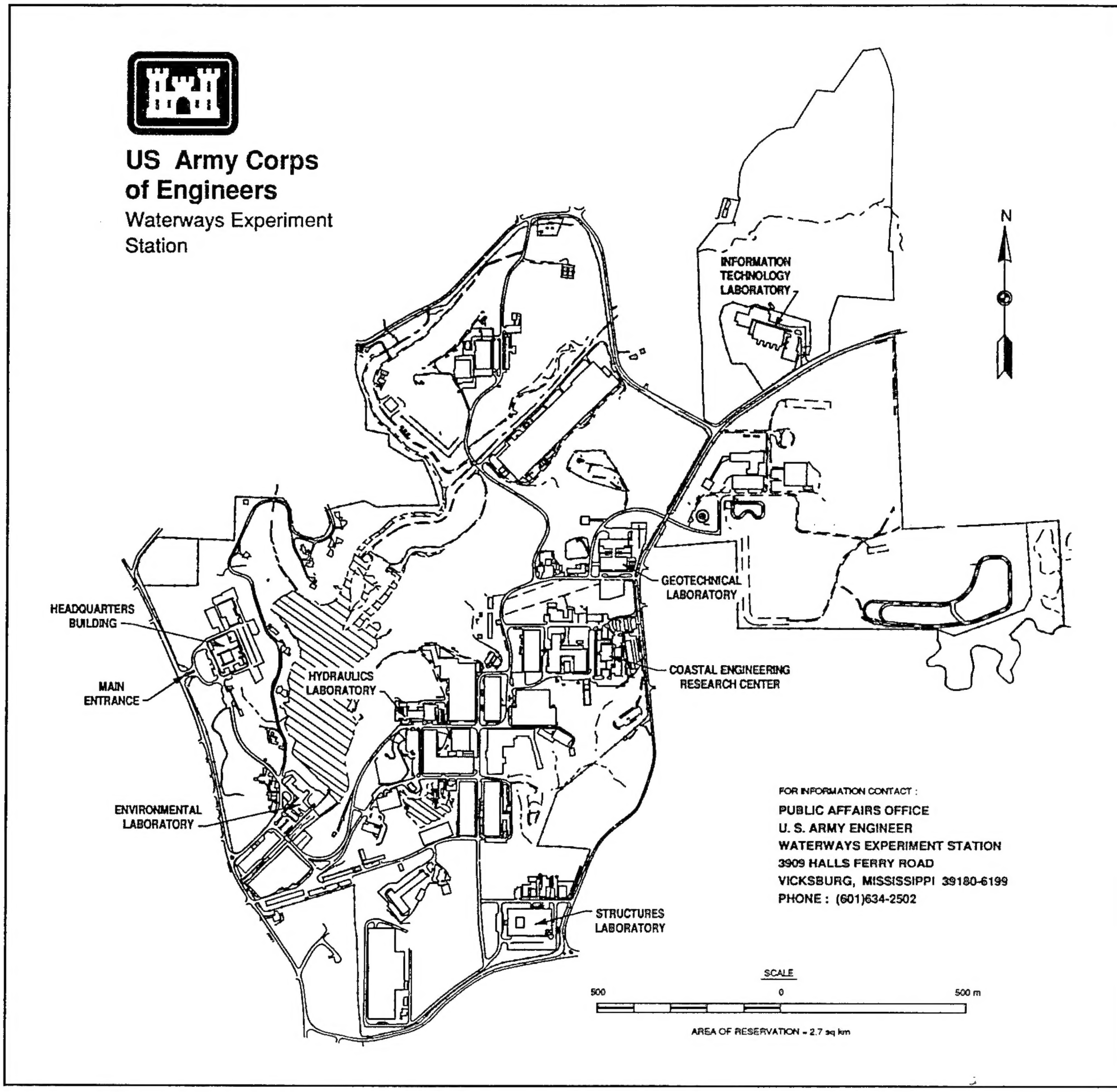
U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Accesion For		
NTIS CRA&I		☒
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Distribution /		
Availability Codes		
Dist	Avail and / or Special	
A-1		

Final report

Approved for public release; distribution is unlimited

Prepared for U.S. Army Engineer Division, New England
Waltham, MA 02254-9149



Waterways Experiment Station Cataloging-in-Publication Data

Bottin, Robert R.

Camp Ellis Beach, Saco Bay, Maine model study of beach erosion : coastal model investigation / by Robert R. Bottin, Jr., Marvin G. Mize, Zeki Demirbilek ; prepared for U.S. Army Engineer Division, New England.

246 p. : ill. ; 28 cm. -- (Technical report ; CERC-95-11)

Includes bibliographic references.

1. Beach erosion -- Maine. 2. Shore protection -- Maine. 3. Breakwaters. 4. Shore protection -- Models. I. Mize, Marvin G. II. Demirbilek, Zeki. III. United States. Army. Corps of Engineers. New England Division. IV. U.S. Army Engineer Waterways Experiment Station. V. Coastal Engineering Research Center (U.S. Army Engineer Waterways Experiment Station) VI. Title. VII. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; CERC-95-11.

TA7 W34 no.CERC-95-11

Contents

Preface

A request for a model investigation to study beach erosion at Camp Ellis Beach, Saco Bay, ME, was initiated by the U.S. Army Engineer Division, New England (NED). Authorization for the U.S. Army Engineer Waterways Experiment Station (WES), Coastal Engineering Research Center (CERC), to perform the study was subsequently granted by Headquarters, U.S. Army Corps of Engineers. Funds were provided by NED on 21 December 1992, 16 December 1993, and 9 May 1994.

Model tests were conducted at WES during the period October 1993 through November 1994 by personnel of the Wave Processes Branch (WPB) of the Wave Dynamics Division (WDD), CERC, under the direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director of CERC, respectively; and under the direct guidance of Messrs. C. E. Chatham, Jr., Chief of WDD; and Dennis G. Markle, Chief of WPB. Tests were conducted by Messrs. William G. Henderson, Computer Assistant, and Marvin G. Mize, Civil Engineering Technician, under the supervision of Mr. Robert R. Bottin, Jr., Project Manager. Numerical studies for wave estimates at the site were conducted by Dr. Zeki Demirbilek, Research Hydraulic Engineer. The main text of this report was prepared by Messrs. Bottin and Mize. Appendix A was prepared by Dr. Demirbilek.

Prior to the model investigation, Messrs. Bottin and Mize met with representatives of CENED and visited Camp Ellis Beach. During the course of the investigation, liaison was maintained by means of conferences, telephone communications, and monthly progress reports. The following personnel visited WES to participate in conferences and observe model operation during the course of the study.

COL Brink Miller	Former Commander, NED
Cathy LeBlanc	NED
Chuck Weiner	NED
Walter Anderson	Maine Geological Survey
Joseph Kelley	Maine Geological Survey
Duncan Fitzgerald	Boston University
John and Judy Reynolds	Camp Ellis Beach
James and Sandra Bastille	Camp Ellis Beach

Dr. Robert W. Whalin was Director of WES during model testing and the preparation and publication of this report. COL Bruce K. Howard, EN, was Commander.

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic meters per second
cubic yards	0.7646	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet per second	0.3048	meters per second
inches	25.4	millimeters
miles (U.S. statute)	1.609347	kilometers
miles per hour	1.609347	kilometers per hour
pounds	0.4536	kilograms
square feet	0.09290304	square meters
square miles	2.589988	square kilometers
tons (2,000 lb)	907.1848	kilograms

1 Introduction

Prototype

Camp Ellis Beach is located along the southern shore of Saco Bay at Saco, ME, approximately 25.7 km (16 miles[1]) south of Portland (Figure 1). Saco Bay has a crescent-shaped shoreline and is about 18.1 km (7 miles) long with Prouts Neck headland to the north and Fletchers Neck headland to the south (Figure 2). The Saco River empties into Saco Bay south of Camp Ellis. Camp Ellis Beach originates at the Saco River north breakwater and extends northerly about 762 m (2,500 ft), where it intersects Ferry Beach.

Camp Ellis is a predominantly residential area, containing very densely settled summer and year-round single-family homes. Most of the homes are one-and-one-half-story or two-story cottage-type houses, although some are larger, permanent residences. The homes are predominantly of older construction; however, some have been refurbished and there is some new construction. In general, the area is characterized by the density of the development and its summer resort quality. In addition to the large number of homes, the Camp Ellis area contains several restaurants, boating facilities, and a fire station.

The Saco River entrance is formed by a breakwater on the north and a jetty on the south. A 2.4-m-deep (8-ft-deep[2]), 61-m-wide (200-ft-wide) entrance channel extends from the ocean through the structures to the mouth of the Saco River. The channel then narrows to 45.7 m (150 ft) in width and extends upstream to the cities of Saco and Biddeford. The north breakwater is 2,030 m (6,660 ft) in length and varies in height. The shoreward 259 m (850 ft) has an el of +5.2 m (+17 ft), the seaward 750 m (2,460 ft) an el of +1.7 m (+5.5 ft), and the remainder of the structure an el of +4.5 m (+15 ft).

---

1 Units of measurement in the text of this report are shown in SI (metric) units, followed by non-SI (British) units in parentheses. In addition, a table of factors for converting non-SI units of measurement used in plates, figures, photos, tabulations, and tables in the report to SI units is presented on page vi.

2 All elevations (el) and depths cited herein are in meters (feet) referred to mean low water (mlw) datum.

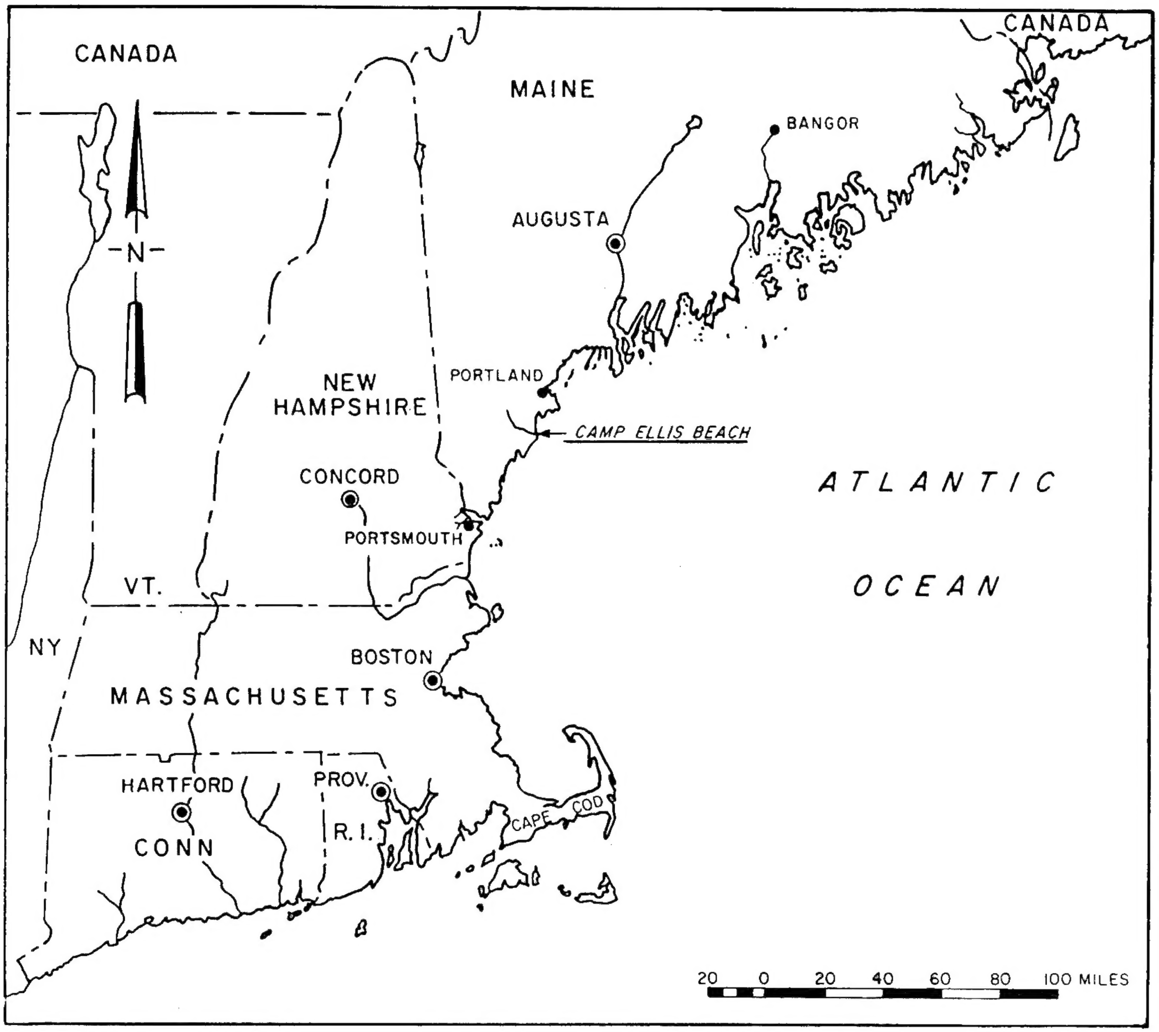


Figure 1. Location map

A 122-m-long (400-ft-long) spur jetty is located about 30.5 m (100 ft) from the shoreward end of the breakwater and extends parallel to shore. The height of the spur jetty varies from +2.6 m (+8.6 ft) at the breakwater to +0.9 m (+3.0 ft) at its northern end. The spur jetty and a stone revetment, which extends north from the breakwater along the shore and then west, were constructed to prevent waves from flanking the north breakwater. The south jetty is 1,463 m (4,800 ft) in length with the shoreward 536 m (1,760 ft) constructed to an el of +3.35 m (+11 ft), and the remainder constructed to a +1.7-m (+5.5-ft) el. A stone revetment extends north from the jetty along the shoreline to the river to prevent flanking of the breakwater by waves. Figure 3 is an aerial view of Camp Ellis Beach and the Saco River structures.

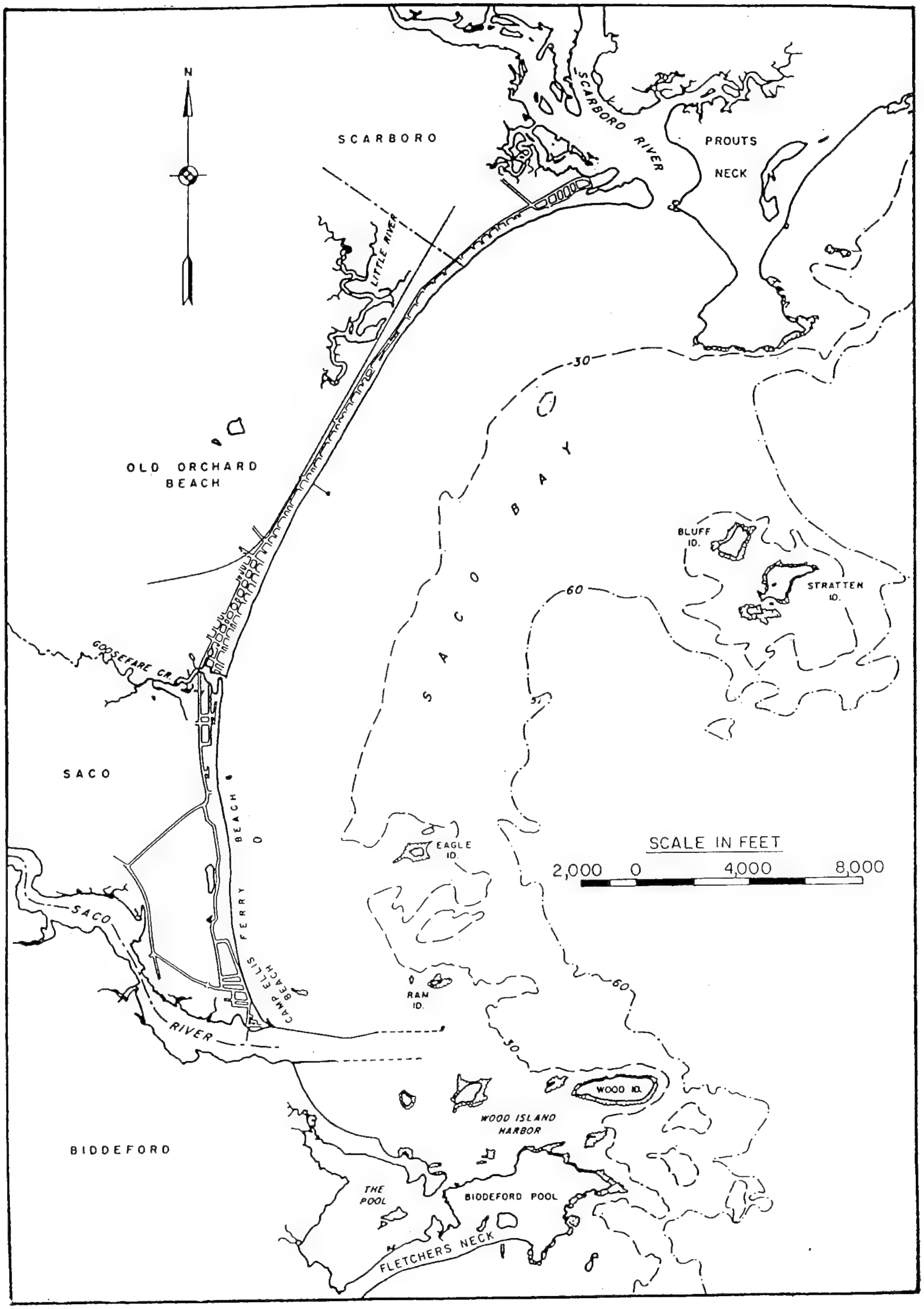


Figure 2. Vicinity map

Figure 3. Aerial view of Camp Ellis Beach and Saco River entrance

History of Breakwater/Jetty Construction

Before the federal project, the Saco River was difficult to navigate since many sharp turns were required to avoid ledges and sandbars. In 1827, Congress authorized construction of 14 piers, the placement of beacons and buoys, and the removal of several obstructions from the river. In 1867, construction of a 1,280-m-long (4,200-ft-long) breakwater north of the river mouth with an el of +3 m (+10 ft) was approved by Congress and subsequently completed. Prior to construction, a single narrow and fairly deep entrance channel -6.1 m ((-20 ft) in throat of entrance) forked into two channels just east of the inlet throat. One channel was 1.2-1.8 m (4-6 ft) deep and oriented in the east-northeasterly direction, with the other 1.2-1.5 m (4-5 ft) in depth and oriented toward the east. Substantial ebb tidal shoals existed adjacent to and between the two channels. Construction of the first segment of the north breakwater in 1867 severed the east-northeasterly channel and paralleled the northern edge of the easterly channel.

During the period 1885-1897 the entire north breakwater was raised to an elevation (el) of +4.5 m (+15 ft). Construction was undertaken to reduce channel shoaling caused by sand flowing over the breakwater during storm wave conditions and to protect against flanking of the breakwater where it

intersected the Camp Ellis shoreline. Raising the structure was accomplished by completing 274-m-long (900-ft-long) sections every 2 or 3 years. Construction began offshore and proceeded landward. During the period 1891-1894, a 1,372-m-long (4,500-ft-long) south jetty was constructed to help stabilize the entrance channel. The jetty was constructed to an el of +1.7 m (+5.5 ft) (termed a "half-tide" jetty since it was mostly underwater at half tide). In 1900 the shoreward 277 m (910 ft) of the south jetty was raised to +3.35 m (+11 ft).

Construction of a 91-m (300-ft) seaward extension of the south jetty (el +1.7 m (+5.5 ft)) was completed in 1912. Also, the 122-m (400-ft) spur jetty off the north breakwater was constructed after a number of destructive northeasterly storms threatened to flank the breakwater. In 1930 a 488-m-long (1,600-ft-long) seaward extension of the north breakwater was completed, and an additional 262-m-long (860-ft-long) extension was completed in 1938. These extensions had crest els of +1.7 m (+5.5 ft). Total lengths of the north breakwater and south jetty in 1938 were 2,030 and 1,463 m (6,660 and 4,800 ft), respectively. Side slopes of the stone structures were 1V:1H.

In 1968, the inshore 259 m (850 ft) of the north breakwater was raised to +5.2 m (+17 ft), resurfaced, and tightened, presumably in response to wash-over of sand into the navigation channel from Camp Ellis Beach during storms, and to guard against a breach at the shoreward end of the structure. Also, an additional 259-m (850-ft) portion of the south jetty (extending seaward) was raised to +3.35 m (+11 ft) in 1969. Revetment work along the shores on both sides of the river was completed to prevent flanking of the structures. The stone revetment along the shore near and north of the north breakwater was completed in 1970, and the revetment along the shore adjacent to and south of the south jetty in 1971.

Problem

Erosion of the shoreline at Camp Ellis Beach has been a serious problem for many years resulting in homes and streets being lost. The area adjacent to the breakwater (approximately 457 m (1,500 ft)) is experiencing erosion at a rate of about 0.9 m/year (3 ft/year), and an adjacent area to the north (about 305 m (1,000 ft)) is receding at a rate of approximately 0.6 m/year (2 ft/year) (USAED, New England 1992). These rates represent average values, and actual erosion varies from year to year. The entire area lacks natural nourishment material. Therefore, storm waves remove the material from the shoreline, and there is no sediment available to renourish the beach. Without improvements, it is assumed that erosion will continue as it has in the past with continued loss of private homes and public infrastructure.

Many have attributed the erosion of the Camp Ellis Beach area to the construction of, and modifications to, both the breakwater and jetty at the mouth of the Saco River. Early studies did not support this conclusion. The last study, however, indicated that construction of the structures at the river mouth

has altered coastal processes in the region (U.S. Army Engineer Waterways Experiment Station (USAEWES) 1991). Historical records indicated that the rate of change of the mean high water line position seemed to correlate with the time of completion of an inshore segment of the raised breakwater sometime between 1895 and 1897. However, severe storms in 1898 and 1909 may also have been major causes of the recorded shoreline recession. The study suggested that the north breakwater's effect on the wave field contributed, to some extent, to erosion of Camp Ellis Beach. Insufficient data existed, however, for making any conclusive statements about the breakwater modification's impact on erosion because of a lack of hydrodynamic and littoral data. The report indicated that the limit of the breakwater's influence on the wave field extends to about 457 m (1,500 ft) north of the structure. There were no conclusive links found between construction of the navigation project and shoreline change north of the Camp Ellis area.

Purpose of the Model Study

At the request of the U.S. Army Engineer Division (USAED), New England (NED), a physical coastal hydraulic model investigation was initiated by WES with the following goals:

a. Study hydrodynamic conditions and qualitative sediment movement patterns at the existing site for various incident wave conditions.

b. Evaluate relative performance of several improvement plans with regard to their effectiveness in reducing erosion and providing a more stable shoreline at the site.

c. Develop remedial plans for the alleviation of undesirable conditions as found necessary.

d. Understand littoral processes at the site, and perform a historical check by reproducing historical bathymetric and structural conditions.

2 The Model

Design of Model

The Camp Ellis Beach model (Figure 4) was constructed to an undistorted linear scale of 1:100, model to prototype. Scale selection was based on the following factors:

a. Depth of water required in the model to prevent excessive bottom friction.

b. Absolute size of model waves.

c. Available shelter dimensions and area required for model construction.

d. Efficiency of model operation.

e. Available wave-generating and wave-measuring equipment.

f. Model construction costs.

A geometrically undistorted model was necessary to ensure accurate reproduction of wave and current patterns. Following selection of the linear scale, the model was designed and operated in accordance with Froude's model law (Stevens et al. 1942). Scale relations used for design and operation of the model were as follows:

Characteristic	Model-Prototype Dimension[1]	Scale Relations
Length	L	L_r = 1:100
Area	L^2	$A_r = L_r^2$ = 1:10,000
Volume	L^3	$\forall_r = L_r^3$ = 1:1,000,000
Time	T	$T_r = L_r^{1/2}$ = 1:10
Velocity	L/T	$V_r = L_r^{1/2}$ = 1:10
Discharge	L^3/T	$Q_r = L_r^{5/2}$ = 1:100,000

[1] Dimensions are in terms of length (L) and time (T).

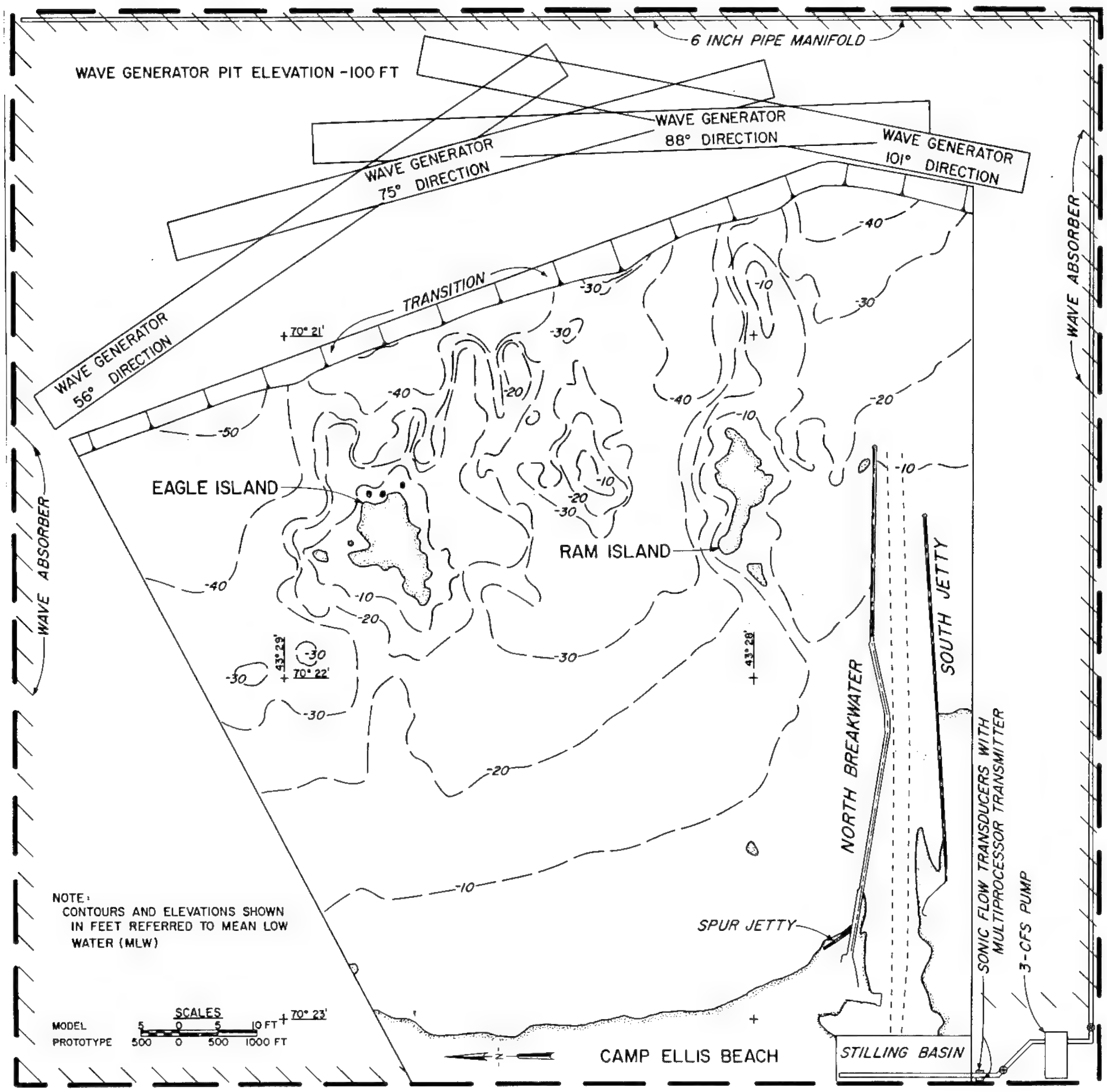


Figure 4. Model layout

The existing breakwater, jetty, and revetments at Saco River and Camp Ellis Beach are rubble-mound structures. Experience and experimental research have shown that considerable wave energy passes through the interstices of this type structure; thus, the transmission and absorption of wave energy was given close consideration during design of the 1:100-scale model. In small-scale hydraulic models, rubble-mound structures reflect relatively more and absorb or dissipate relatively less wave energy than geometrically similar prototype structures (LeMehaute 1965). Also, the transmission of wave energy through a rubble-mound structure is relatively less for the small-scale model than for the prototype. Consequently, some adjustment in small-scale model rubble-mound structures is needed to ensure satisfactory reproduction of wave-reflection and wave-transmission characteristics. In past investigations at WES (Dai and Jackson 1966, Brasfeild and Ball 1967), this adjustment was

made by determining the wave-energy transmission characteristics of the proposed structure in a two-dimensional model using a scale large enough to ensure negligible scale effects. A section then was developed for the small-scale, three-dimensional model that would provide essentially the same relative transmission of wave energy. Therefore, from previous findings for structures and wave conditions similar to those at Saco River and Camp Ellis Beach, it was determined that a close approximation of the correct wave-energy transmission characteristics could be obtained by increasing the size of the rock used in the 1:100-scale model to approximately two times that required for geometric similarity. Accordingly, in constructing the rubble-mound structures in the Camp Ellis Beach model, rock sizes were computed linearly by scale, then multiplied by two to determine the actual sizes to be used in the model.

Ideally, a quantitative, three-dimensional, movable-bed model investigation would best determine the erosion and sediment patterns at Camp Ellis Beach. However, this type of model investigation is difficult and expensive to conduct, and each area in which such an investigation is contemplated must be carefully analyzed. The following computations and prototype data are considered essential for such investigations (Chatham, Davidson, and Whalin 1973):

a. Computation of the littoral transport, based on the best available wave statistics.

b. Analysis of the sand-size distribution over the entire project area (offshore to a point well beyond the breaker zone).

c. Simultaneous measurements of the following items over a period of erosion of the shoreline (this measurement period should be judiciously chosen to obtain the maximum probability of erosion during as short a time span as possible):

    (1) Continuous measurements of incident-wave characteristics. Such measurements would mean placing enough redundant sensors to accurately estimate the directional spectrum over the entire project area, and in addition, would mean conducting a rather sophisticated analysis of all these data.

    (2) Bottom profiling of the entire project area using the shortest time intervals possible.

    (3) Nearly continuous measurements of both littoral and onshore-offshore transport of sand. A wave-forecast service would be essential to this effort to prepare for full operation during the erosion period.

As indicated, large amounts of prototype data are needed to conduct movable-bed model studies. These data were non-existent for the Camp Ellis Beach area. Currently, state-of-the-art in movable-bed modeling tends to be restricted

to research and development studies as opposed to site specific project studies. In view of the complexities and unknowns involved in conducting movable-bed model studies and due to limited funds and time for the Camp Ellis Beach project, the model was molded in cement mortar (fixed-bed) and a tracer material was prepared to qualitatively define erosion and sediment patterns along the beach.

Model and Appurtenances

The model reproduced about 2,438 m (8,000 ft) of the Saco Bay shoreline, Camp Ellis Beach, the Saco River entrance, and bathymetry in Saco Bay to an offshore depth averaging about -13.7 m (-45 ft) with a sloping transition to the wave generator pit el of -30.5 m (-100 ft). The total area reproduced in the model was approximately 1.952 m^2 (21,000 ft^2) representing about 19.4 km^2 (7.5 square miles) in the prototype. A general view of the model is shown in Figure 5. Vertical control for model construction was based on mean low water (mlw). Horizontal control was referenced to a local prototype grid system.

Model waves were generated by a 24.4-m-long (80-ft-long), unidirectional spectral, electrohydraulic, wave generator with a trapezoidal-shaped, vertical-motion plunger. Vertical motion of the plunger was controlled by a computer-generated command signal, and movement of the plunger caused a displacement of water which generated required test waves. The wave generator was mounted on retractable casters which enabled it to be positioned to generate waves from required directions.

A water circulating system (Figure 4) consisting of 152-mm (6-in.) perforated-pipe water-intake and discharge manifolds, a 0.085-cms (3-cfs) pump, and sonic flow transducers with a multiprocessor transmitter, was used in the model to reproduce steady-state flows through the river channel that corresponded to selected prototype river discharges.

An Automated Data Acquisition and Control System, designed and constructed at WES (Figure 6), was used to generate and transmit control signals, monitor wave generator feedback, and secure and analyze wave data at selected locations in the model. Through the use of a microvax computer, the electrical output of parallel-wire, capacitance-type wave gages, which varied with the change in water-surface elevation with respect to time, was recorded on magnetic disks. These data then were analyzed to obtain the parametric wave data.

A 0.6-m (2-ft) (horizontal) solid layer of fiber wave absorber was placed around the inside perimeter of the model to dampen wave energy that might otherwise be reflected from the model walls. In addition, guide vanes were placed along the wave generator sides in the flat pit area to ensure proper formation of the wave train incident to the model contours.

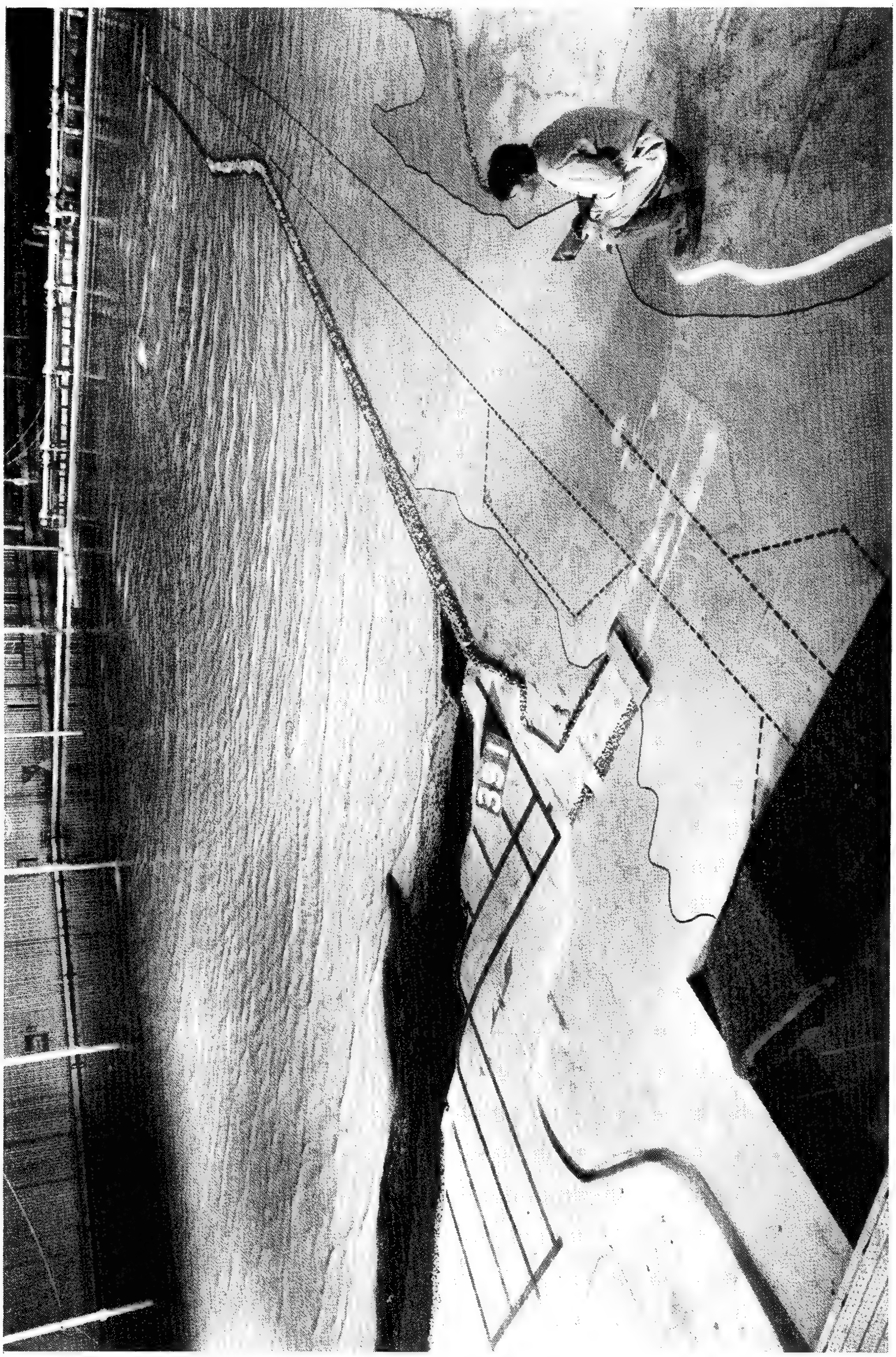


Figure 5. General view of model

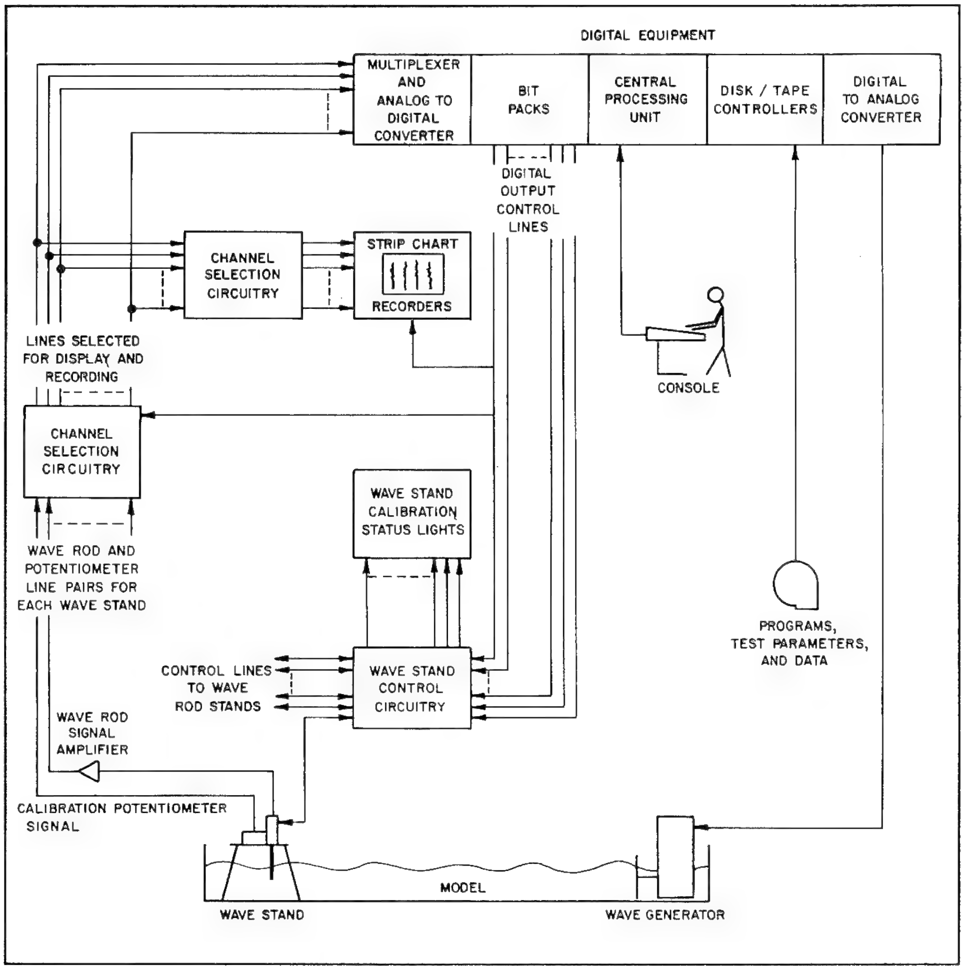


Figure 6. Automated Data Acquisition and Control System

Design of Tracer Material

As discussed previously, a fixed-bed model was constructed and a tracer material designed and prepared to qualitatively determine movement and deposition of sediment in the vicinity of Camp Ellis Beach. Tracer was chosen in accordance with the scaling relations of Noda (1972), which indicate a relation or model law among the four basic scale ratios, i.e., the horizontal scale λ; the vertical scale μ; the sediment size ratio n_D; and the relative specific weight ratio n_γ. These relations were determined experimentally using a wide range of wave conditions and bottom materials and are valid mainly for the breaker zone.

Noda's scaling relations indicate that movable-bed models with scales in the vicinity of 1:100 (model to prototype) should be distorted (i.e., they should have different horizontal and vertical scales). Since the fixed-bed model of Camp Ellis Beach was undistorted to allow accurate reproduction of

short-period wave and current patterns, the following procedure was used to select a tracer material. Using the prototype sand characteristics (median diameter, D_{50} = 0.52 mm (0.02 in.), specific gravity = 2.65) and assuming the horizontal scale to be in similitude (i.e., 1:100), the median diameter for a given specific gravity of tracer material and the vertical scale were computed. The vertical scale was then assumed to be in similitude and the tracer median diameter and horizontal scale were computed. This resulted in a range of tracer sizes for given specific gravities that could be used. Although several types of movable-bed tracer materials were available at WES, previous investigations (Giles and Chatham 1974, Bottin and Chatham 1975) indicated that crushed coal tracer more nearly represented movement of prototype sand. Therefore, quantities of crushed coal (specific gravity = 1.30; median diameter, D_{50} = 1.18 mm (0.046 in.)) were prepared for use as a tracer material throughout the model investigation.

3 Test Conditions and Procedures

Selection of Test Conditions

Still-water level

Still-water levels (swl's) for wave action models are selected so that various wave-induced phenomena that are dependent on water depths are accurately reproduced in the model. These phenomena include refraction of waves in the project area, overtopping of structures by waves, reflection of wave energy from various structures, and transmission of wave energy through porous structures.

In most cases, for the following reasons, it is desirable to select a model swl that closely approximates the higher water stages that normally occur in the prototype:

a. The maximum amount of wave energy reaching a coastal area normally occurs during the higher water phase of the local tidal cycle.

b. Most storms moving onshore are characteristically accompanied by a higher water level due to wind, tide, and shoreward mass transport.

c. The selection of a high swl helps minimize model scale effects due to viscous bottom friction.

d. When a high swl is selected, a model investigation tends to yield more conservative results.

The Maine coast experiences semidiurnal tides, which are two high and two low tides each lunar day (approximately 24 hr, 50 min). Tidal data representative of the Camp Ellis Beach site are shown below (USAED, New England 1992):

Parameter	Meters (Feet)
Maximum astronomic high water	+3.4 (+11.1)
Mean spring high water	+2.8 (+9.3)
Mean high water	+2.7 (+8.8)
Mean tide level	+1.3 (+4.4)
Mean low water	0.0 (0.0)
Mean spring low water	-0.2 (-0.6)
Minimum astronomic high water	-0.7 (-2.3)

Swl's of 0.0, +2.7, +3.7, and +4.1 m (0.0, +8.8, +12.0, and +13.6 ft) were selected by NED for use in testing the Camp Ellis Beach model. The 0.0- and 2.7-m (0.0- and +8.8-ft) values were representative of mlw and mean high water (mhw), respectively, and were used for most model tests. The +3.7- and +4.1-m (+12.0- and +13.6-ft) values were used while testing severe storm wave conditions. These swl's coincided with major storms at Camp Ellis Beach (Hubertz and Curtis 1993) that occurred in 1991 (Halloween Storm of 1991) and 1978 (Blizzard of 1978), respectively.

Factors influencing selection of test wave characteristics

In planning the testing program for a model investigation of wave-action problems, it is necessary to select heights, periods, and directions for the test waves that will allow a definition of existing conditions, realistic testing of proposed improvement plans, and an accurate evaluation of the elements of the various proposals. Surface-wind waves are generated primarily by the interactions between tangential stresses of wind flowing over water, resonance between the water surface and atmospheric turbulence, and interactions between individual wave components. The height and period of the maximum significant wave that can be generated by a given storm depend on the wind speed, the length of time that wind of a given speed continues to blow, and the distance over water (fetch) which the wind blows. Selection of test wave conditions entails evaluation of such factors as:

a. Fetch and decay distances (the latter being the distance over which waves travel after leaving the generating area) for various directions from which waves can approach the problem area.

b. Frequency of occurrence and duration of storm winds from the different directions.

c. Alignment, size, and relative geographic position of the navigation structures.

d. Alignments, lengths, and locations of the various reflecting surfaces in the area.

e. Refraction of waves caused by differentials in depth in the area seaward of the site, which may create either a concentration or a diffusion of wave energy.

Storms and wave data

Two distinct types of storms influence coastal processes in New England. These are extratropical and tropical cyclones, distinguished primarily by their place of origin. Extratropical cyclones are the most frequent variety occurring in New England. These storms derive their energy from temperature contrast between cold and warm air masses. Low pressure centers frequently form or intensify along the boundary between cold dry continental air masses and warm marine air masses off the coasts of Georgia and the Carolinas and move northeasterly more or less parallel to the coast. Depending on the track of the storm, high onshore winds may be generated from northeast clockwise through southeast resulting in large waves and extreme storm surge. Tropical cyclones form in warm moist masses over the Caribbean and the waters adjacent to the west coast of Africa. Energy for these storms is provided by the latent heat of condensation. When the maximum wind speed in a tropical cyclone exceeds 121 km/hr (75 mph), it is classified as a hurricane. Tropical cyclones and hurricanes affecting the New England coast generally approach from the south and the east, and may result in great wave and surge action. The hurricane and tropical storm season in New England generally extends from August through October.

Measured prototype wave data covering a sufficiently long duration from which to base a comprehensive statistical analysis of deepwater wave conditions for the Camp Ellis Beach area were not available. However, statistical wave hindcast estimates representative of this area were obtained from the WES Wave Information Studies (WIS), which includes a 20-yr hindcast period (1956-1975). The hindcast (Hubertz et al. 1993) was obtained at WIS station 99 (43.50N, 70.25W) in the North Atlantic Sea. Data obtained at the deepwater station are presented in Table 1. These data indicate that the majority of waves approach Camp Ellis Beach from the 103-deg (approximately east-southeast) direction. Hindcast simulations were performed to determine wave characteristics at the station resulting from severe storms (i.e., the Blizzard of 1978 and the Halloween Storm of 1991). Maximum deepwater waves at the hindcast station during the storms (Hubertz and Curtis 1993) were: 13-sec, 7.9-m (26-ft) waves from 78 deg for the 1978 storm and 15-sec, 6.1-m (20-ft) waves from 80 deg for the 1991 storm.

Wave refraction

When waves move into water of gradually decreasing depth, transformations take place in all wave characteristics except wave period (to the first order of approximation). The most important transformations with respect to the selection of test wave characteristics are the changes in wave height and direction of travel due to the phenomenon referred to as wave refraction. When the refraction coefficient K_r is determined, it is multiplied by the shoaling coefficient K_s, which gives a conversion factor of deepwater wave heights to shallow-water values. The shoaling coefficient, a function of wave length and water depth, can be obtained from the *Shore Protection Manual* (1984). The change in wave height and direction may be determined by using a numerical combined refraction/diffraction (REFDIF) model. REFDIF was selected to transform wave characteristics at the deepwater station to values at the approximate location of the wave generator (shallow-water characteristics) in the physical model. This model is suitable especially for varying bathymetry in domains which include islands and are surrounded by complex land boundaries. Table 2 summarizes the refraction/diffraction analysis. The wave height adjustment factor can be applied to any deepwater wave height to obtain corresponding shallow-water values. Details of the REFDIF analysis are presented in Appendix A. Based on the refracted directions secured at the approximate locations of the wave generator in the model, the following test directions (deepwater direction and corresponding shallow-water direction) were selected for use during model testing.

Deepwater Direction deg	Selected Shallow-Water Direction deg
Hindcast Waves	
45	56
67.5	75
90	88
103	101
Storm Waves	
80	88
78	88

Selection of test waves

WIS hindcast data (Table 1) and storm data were converted to shallow-water values by application of the wave height adjustment factor (Table 2) and are shown in Table 3. Characteristics of test waves selected for use in the model investigation are shown in the following tabulation:

Direction, deg	Period, sec	Height, ft	swl, ft
56	5	4	0.0, +8.8
	7	4	
75	5	6	0.0, +8.8
	7	6, 10	
	9	4, 8	
	11	6, 10, 14	
88	5	6	0.0, +8.8
	7	6, 10	
	9	4, 8, 12	
	11	6, 10, 14, 18	
	13	6, 10, 14, 18	
	15	18	+12.0
	13	20	+13.6
	15	16	0.0, +8.8
101	5	6	0.0, +8.8
	7	8	
	9	4, 8, 12	
	11	6, 10	
	13	4, 8, 12	
	15	4, 8, 12	
	17	6	
* Wave conditions generated on contours landward of model transition.			

Unidirectional wave spectra were generated (based on Joint North Sea Wave Project (JONSWAP) parameters) for the selected test waves and used throughout the model investigation. Plots of typical wave spectra are shown in Figure 7. The solid line represents the desired spectra, while the dashed line represents the spectra reproduced in the model. A generic JONSWAP gamma function of 3.3 was used to determine the spread of the spectra. The larger the gamma value, the sharper the peak in the energy distribution curve. A typical wave time series is shown in Figure 8, which depicts water surface elevation η versus time. Selected test waves were significant wave heights, the average height of the highest one-third of the waves or H_s. In deep water, H_s is very similar to H_{mo} (energy-based wave), where $H_{mo} = 4\ (E)^{1/2}$ and E equals total energy in the spectra, which is obtained by integrating the energy density spectra over the frequency range.

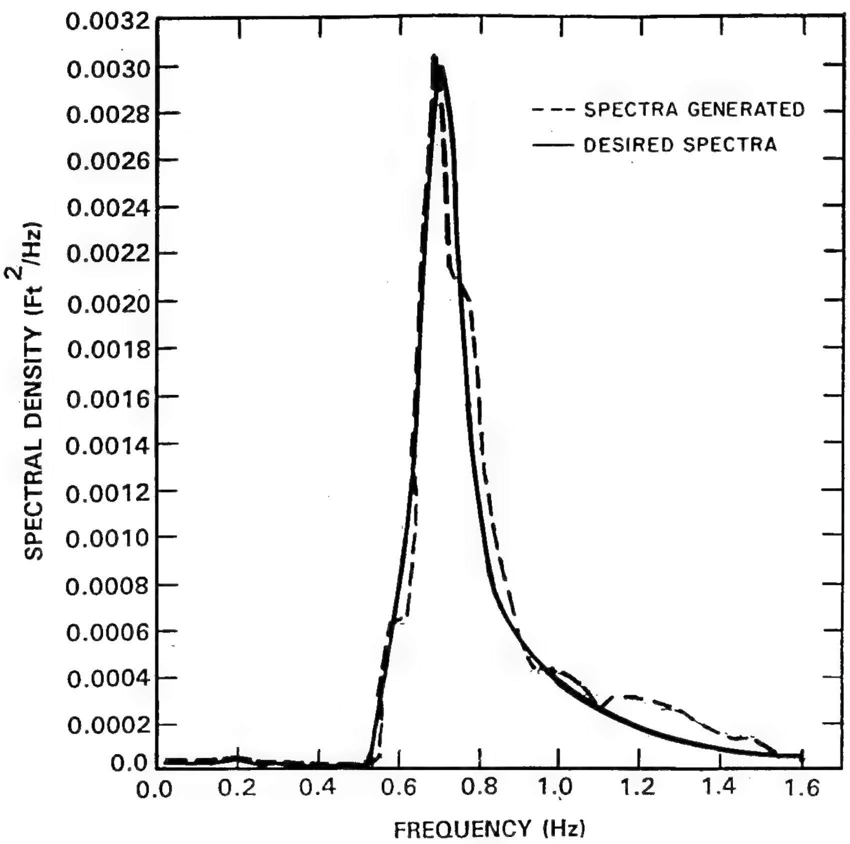


Figure 7. Typical energy density versus frequency plots (model terms) for a wave spectra; 13-sec, 12-ft waves

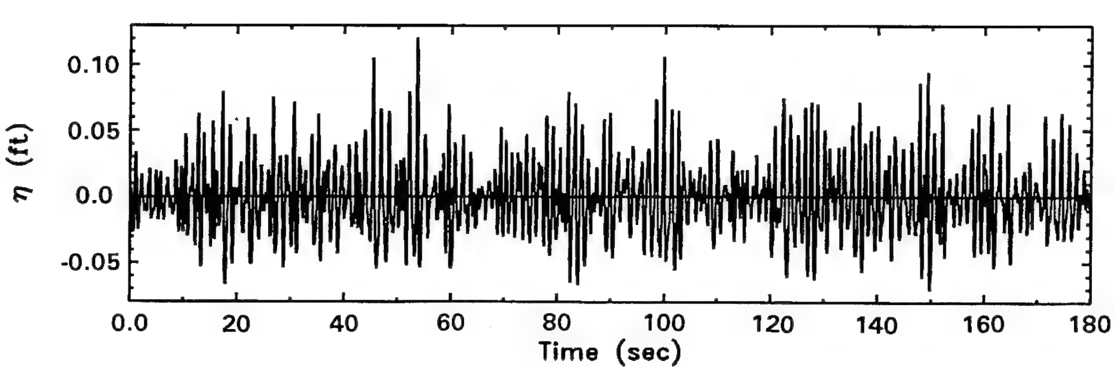


Figure 8. Typical model wave train time series, 13-sec, 12-ft test waves

River discharges

The Saco River drains an area of approximately 44,030 km^2 (17,000 square miles), and the mean discharge at the river mouth is 91 m^3/s (3,200 cfs) (USAED, New England 1967). Maximum flow measured by the U.S. Geological Survey was 535 m^3/s (18,900 cfs), and minimum flow was 22 m^3/s (765 cfs) at Cornish, ME, during 1976 (USAED, New England 1978). The 91-m^3/s (3,200-cfs) river discharge at the river mouth was selected for model testing. It was used for one test plan and for historical tests during the conduct of the model investigation.

Analysis of Model Data

Relative merits of the various plans tested were evaluated by the following criteria:

a. Comparison of sediment tracer movement and subsequent deposits.

b. Comparison of wave heights at selected locations in the model.

c. Comparison of current patterns and magnitudes at the site.

d. Visual observations and wave pattern photographs.

In the time domain wave-height data analysis, the average height of the highest one-third of the waves H_s, recorded at each gage location, was computed. All wave heights were then adjusted by application of Keulegan's equation[1] to compensate for excessive model wave height attenuation due to viscous bottom friction. From this equation, reduction of model wave heights (relative to the prototype) can be calculated as a function of water depth, width of wave front, wave period, water viscosity, and distance of wave travel. Model data can then be corrected and converted to their prototype equivalents.

---

[1] G. H. Keulegan, 1950, "The Gradual Damping of a Progressive Oscillatory Wave with Distance in a Prismatic Rectangular Channel," Unpublished data, National Bureau of Standards, Washington, DC, prepared at request of Director, WES, Vicksburg, MS, by letter of 2 May 1950.

4 Tests and Results

Tests

Existing conditions

Prior to testing of the various improvement plans, comprehensive tests were conducted for existing conditions (Plate 1) to establish a base from which to evaluate the effectiveness of the test plans. Wave-height data, sediment tracer patterns, wave-induced current patterns and magnitudes, and wave pattern photos were secured along Camp Ellis Beach for test waves from all four test directions.

Improvement plans

Initially, proposed improvement plans consisted of roughening a portion of the existing Saco River north breakwater adjacent to Camp Ellis Beach, and installing a beachfill and offshore berms. After initiation of the study, tests were added to evaluate spur jetties and removal of the existing north breakwater. Wave heights, sediment tracer patterns, wave-induced current patterns and magnitudes, and/or wave patterns were secured for nine proposed improvement plans. Brief descriptions of the test plans are presented in the following subparagraphs; dimensional details are shown in Plates 2-8. Typical cross sections for various elements of Plans 1-8 are presented in Plate 9.

a. Plan 1 (Plate 2) consisted of roughening a 259-m-long (850-ft-long) portion of the north breakwater adjacent to Camp Ellis Beach. The structure was roughened by placement of 907- to 1,814-kg (1-to 2-ton) stone along the seaward side of the breakwater on a 1V:2H side slope. The crest of the new stone structure was 2.4 m (8 ft) in width with an el of +5.2 m (+17 ft).

b. Plan 2 (Plate 3) entailed the placement of a beach fill adjacent to Camp Ellis Beach in concert with the existing north breakwater. The beach fill el was +4.6 m (+15 ft) with a 1V:15H slope extending seaward.

c. Plan 3 (Plate 3) involved the roughened breakwater of Plan 1 in conjunction with the beach fill of Plan 2.

d. Plan 4 (Plate 4) consisted of an offshore berm installed at the approximate -3.0-m (-10-ft) contour. The submerged berm represented about 152,920 cu m (200,000 cu yd) of sand and was 350 m (1,150 ft) long with a crest width of 91.4 m (300 ft). Its crest height was -1.2 m (-4 ft) and the berm had 1V:50H side slopes.

e. Plan 5 (Plate 5) involved an offshore berm installed at approximately the -4.6-m (-15-ft) contour. The submerged berm represented about 76,460 cu m (100,000 cu yd) of sand and was 190.5 m (625 ft) long with a crest width of 30.5 m (100 ft). Its crest el was -1.8 m (-6 ft) with 1V:25H side slopes.

f. Plan 6 (Plate 6) consisted of the installation of a 914-m-long (3,000-ft-long) stone spur jetty. The spur jetty originated from the north breakwater and extended north parallel to Camp Ellis Beach shoreward of the -3-m (-10-ft) contour. The crest el of the jetty was +3 m (+10 ft) and it had 1V:1.5H side slopes.

g. Plan 7 (Plate 7) entailed the 914-m-long (3,000-ft-long) spur jetty of Plan 6, but the crest el was raised from +3 to +4.6 m (+10 to +15 ft).

h. Plan 8 (Plate 7) involved the +4.6-m-high (+15-ft-high) spur jetty of Plan 7, but the jetty length was decreased from 914 to 457 m (3,000 to 1,500 ft).

i. Plan 9 (Plate 8) consisted of the removal of the entire existing north breakwater.

Historical erosion tests

To better understand littoral processes at the study site, historical tests were conducted after testing of improvement plans. Sediment tracer tests, both with and without river flow conditions, were conducted for three historical test series. Initial tests involved the natural pre-breakwater condition of 1866 (Plate 10). The original north breakwater completed in 1873 (crest el +3 m (+10 ft) then was tested (Plate 11), followed by raising the initial structure to +4.6 m (+15 ft) in el (Plate 12), which was accomplished in 1897, and construction of a south jetty (completed 1894). Offshore contours were remolded in cement mortar to 1866 conditions for the historical tests; however, sediment along the river mouth and adjacent to Camp Ellis Beach was molded in tracer material to 1866 conditions to qualitatively determine sediment movement patterns for the range of conditions tested.

Wave height tests and wave patterns

Wave height tests and representative wave patterns for existing conditions and some of the improvement plans (Plans 1 and 6-9) were conducted for test waves from one or more of the selected test directions. Tests involving some test plans, however, were limited to the most critical directions of wave approach (i.e., 101 and 88 deg). Wave gage locations for existing conditions, Plan 1, and Plans 6-9 are shown in Plates 1-2 and 6-8.

Wave-induced current patterns and magnitudes

Wave-induced current patterns and magnitudes were determined at selected locations in the model by timing the progress of an injected dye tracer relative to a graduated scale placed on the model floor. These tests were conducted for existing conditions and selected improvement plans for representative test waves from one or more of the test directions.

Sediment tracer tests

Sediment tracer tests were conducted for existing conditions, all improvement plans, and historical conditions. Tracer material was introduced along the Camp Ellis Beach shoreline for some conditions. A known amount of tracer material was subjected to identical test conditions for existing conditions and various plans so that test results would have a common base for comparison. In other cases (i.e., beach fills, offshore berms, and historical plans), the actual structure or shoal was molded in sediment tracer material. These tests were conducted to determine sediment tracer movement patterns and subsequent deposits. Some test plans were limited to waves from the most critical incident direction of wave approach (i.e., 101 deg) with respect to erosion of the shoreline.

Test Results

In evaluating test results, relative merits of the various improvement plans were based on an analysis of measured wave heights in the Camp Ellis Beach vicinity, the movement of tracer material and subsequent deposits, wave-induced current patterns and magnitudes, and visual observations. Model wave heights (significant wave height or H_s) were tabulated to show measured values at selected locations. Wave-induced current patterns and magnitudes were superimposed onto wave pattern photographs for the corresponding conditions tested. General movement of tracer material and subsequent deposits also were documented in photographs. Arrows were superimposed onto photographs to define sediment movement patterns.

Existing conditions

Results of wave height tests conducted for existing conditions are presented in Table 4 for test waves from the four test directions and four swl's. For the 0.0-m (0.0-ft) swl, maximum wave heights[1] along Camp Ellis Beach (Gages 1-6) were 1.50, 1.28, 0.64, and .006 m (4.9, 4.2, 2.1, and 0.2 ft) for the 101-, 88-, 75-, and 56-deg directions, respectively. Maximum wave heights for the +2.7-m (+8.8-ft) swl were 2.78, 2.78, 2.48, and 0.8 m (8.9, 8.9, 7.9, and 2.6 ft) along Camp Ellis Beach, respectively, for the 101-, 88-, 75-, and 56-deg directions. Maximum wave heights along the beach for the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's were 2.7 and 3.3 m (8.7 and 10.8 ft), respectively, for test waves from 88 deg. Visual observations during testing revealed reflected waves off the sand-tightened portion of the north breakwater back toward Camp Ellis Beach.

Wave-induced current patterns and magnitudes for existing conditions are shown in Photos 1-19 for representative waves from all directions and swl's. For all test conditions currents adjacent to the beach moved in a northerly direction. Maximum velocities obtained along the beach were 0.9, 0.94, 0.76, and 0.003 m/s (2.9, 3.1, 2.5, and 0.1 fps) for the 101-, 88-, 75-, and 56-deg directions, respectively. Typical wave patterns obtained for existing conditions also are shown in Photos 1-19.

General movement of tracer material in the vicinity of Camp Ellis Beach for existing conditions is shown in Photos 20-34. Each photo represents the progression of sediment tracer movement (model time) for the particular test condition shown. For test waves from 101, 88, and 75 deg, sediment tracer material moved northerly for the +2.7-m (+8.8-ft) swl. The more severe waves resulted in material moving out of the area at an increased rate. For extreme storm waves from 88 deg with the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's, sediment material was washed up on the overbank of the model due to significant runup. In general, tracer material did not move out of the immediate Camp Ellis Beach area for test waves with the 0.0-m (0.0-ft) swl. Also, for test waves from 56 deg with the +2.7-m (+8.8-ft) swl, sediment tracer material remained in the immediate vicinity of Camp Ellis Beach.

Improvement plans

Wave height test results obtained for Plan 1 are presented in Table 5 for test waves from the four test directions and four swl's. For the 0.0-m (0.0-ft) swl, maximum wave heights along Camp Ellis Beach (Gages 1-6) were 1.64, 1.2, 0.64, and 0.15 m (5.4, 3.9, 2.1, and 0.5 ft) for the 101-, 88-, 75-, and 56-deg directions, respectively. Maximum wave heights for the +2.7-m (+8.8-ft) swl were 2.43, 2.7, 2.2, and 0.79 m (8.0, 8.9, 7.2, and 2.6 ft) along Camp Ellis Beach for the 101-, 88-, 75-, and 56-deg directions, respectively.

---

[1] Refers to maximum significant wave heights throughout report.

Maximum wave heights along Camp Ellis Beach for the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's were 2.5 and 3.2 m (8.1 and 10.5 ft), respectively, for test waves from 88 deg. From visual observations, it appeared that the roughened breakwater section of Plan 1 reduced the reflected wave energy in the vicinity of the beach.

Wave-induced current patterns and magnitudes for Plan 1 are shown in Photos 35-53 for representative test waves from all four directions and swl's. For all test conditions, currents along Camp Ellis Beach moved in a northerly direction. Maximum velocities obtained along the beach were 0.61, 0.94, 0.61, and 0.03 m/s (2.0, 3.1, 2.0, and 0.1 fps) for the 101-, 88-, 75-, and 56-deg directions, respectively. Typical wave patterns obtained for Plan 1 also are shown in Photos 35-53.

The general movement of tracer material at Camp Ellis Beach with Plan 1 installed is shown in Photos 54-68 for representative test waves from the various directions. For test waves from 101, 88, and 75 deg with the +2.7-m (+8.8-ft) swl, sediment tracer material migrated in a northerly direction with the more severe test wave conditions resulting in erosion at a faster rate. Severe storm waves with the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's resulted in significant runup with sediment material washing up on the overbank, similar to results obtained for existing conditions. For the 0.0-m (0.0-ft) swl, tracer material did not move out of the immediate area. For test waves from 56 deg, sediment remained in the immediate vicinity of Camp Ellis Beach with the +2.7-m (+8.8-ft) swl.

General movement of tracer material in the vicinity of Camp Ellis Beach for the Plan 2 beachfill is shown in Photo 69 for 13-sec, 3.7-m (12-ft) test waves from 101 deg with the +2.7-m (+8.8-ft) swl. The beach fill eventually eroded to the original shoreline with sediment moving in a northerly direction. Sediment tracer material movement with the roughened breakwater and beachfill of Plan 3 is shown in Photo 70 for the same test conditions. Again, the beachfill moved north and eroded to the shoreline. The roughened breakwater had little effect on the rate of sediment movement to the north.

The 152,920-cu-m (200,000-cu-yd) submerged Plan 4 berm is shown in Photo 71 prior to testing. All tests were conducted for the +2.7-m (+8.8-ft) swl, and the berm was subjected to representative test waves from 101, 88, 75, and then again for 101 deg for a cumulative time of 15 hr. The general movement of the berm after 2.5 and 5 hr of testing with 13-sec, 3.7-m (12-ft) waves from 101 deg is shown in Photos 72 and 73, respectively. Progression of berm migration after additional testing with 13-sec, 5.5-m (18-ft) test waves from 88 deg for 3 hr and 11-sec, 4.3-m (14-ft) test waves from 75 deg for 3 hr is shown in Photos 74 and 75, respectively. An additional 4 hr testing with 13-sec, 3.7-m (12-ft) waves from 101 deg resulted in the migration pattern shown in Photo 76. The berm material moved toward Camp Ellis Beach for all the test waves. Tracer material also was placed along the shoreline prior to testing of the submerged berm. General movement of tracer material along Camp Ellis Beach for 13-sec, 3.7-m (12-ft) test waves from 101 deg during the

first 2.5 hr of testing is shown in Photo 77. The shoreline remained slightly more stable than it did for the same test conditions for existing conditions (Photo 22). The berm initially decreased the level of wave energy reaching the shoreline and resulted in a decrease in the rate of erosion along the shoreline. Sediment tracer along the shoreline after 5 to 15 hr of testing is shown in Photo 78. It was noted that the berm material actually began feeding the beach after 8 hr, but continued exposure to wave action resulted in the loss of berm protection and the northerly movement of material out of the Camp Ellis Beach area.

The 76,460-cu-m (100,000-cu-yd) submerged Plan 5 berm is shown in Photo 79 prior to testing. Similar to the Plan 4 berm, all tests were conducted with a +2.7-m (+8.8-ft) swl for representative test waves from 101, 88, 75, and 101 deg, respectively, for a cumulative time of 15 hr. Migration of the berm after 2.5 and 5 hr of testing, respectively, is shown in Photos 80 and 81. Progression of berm movement after additional testing with 13-sec, 3.7-m (12-ft) waves from 88 deg for 3 hr and 11-sec, 4.3-m (14-ft) waves from 75 deg for 3 hr is shown in Photos 82 and 83, respectively. An additional 4 hr testing with 13-sec, 3.7-m (12-ft) waves from 101 deg resulted in the migration pattern as shown in Photo 84. The berm material moved toward Camp Ellis Beach for all test waves. Sediment tracer material was placed along the shoreline prior to testing of the submerged berm. The general movement of material along Camp Ellis Beach for 13-sec, 3.7-m (12-ft) test waves from 101 deg during the initial 2.5 hr of testing is shown in Photo 85. The shoreline appeared to erode at about the same rate as it did for existing conditions for the same test conditions (Photo 22). Sediment tracer movement along the shoreline is shown in Photo 86 after 5 to 15 hr of testing. Berm material began feeding the beach after 8 hr, but additional exposure to wave action resulted in material eventually moving to the north.

Results of wave height tests conducted for Plan 6 are presented in Table 6 for test waves from 101 deg with the +2.7-m (+8.8-ft) swl. Maximum wave heights along Camp Ellis Beach (Gages 1-6) were 1.5 m (4.8 ft) for 15-sec, 4.3-m (14-ft) test waves. Even though massive overtopping of the structure was observed for some test waves, the spur was effective in reducing wave heights along the shoreline, relative to those obtained for existing conditions (maximum wave heights of 2.7 m (8.9 ft) for the +2.7-m (+8.8-ft) swl for test waves from 101 deg). Typical wave patterns with Plan 6 installed in the model are shown in Photo 87.

General movement of tracer material along the beach for Plan 6 is shown in Photos 88 and 89 for 13-sec, 3.7-m (12-ft) test waves from 101 deg with the +2.7-m (+8.8-ft) swl. Photo 88 presents movement of tracer material for the first 2.5 hr of the test, and Photo 89 shows tracer movement between 3 and 8 hr. Tracer material moved toward the shoreline and then began migrating north. The Plan 6 spur resulted in erosion at a much lesser rate than existing conditions; however, test results indicated the material along the beach would erode after continued exposure to wave action.

Wave height test results obtained for Plan 7 are presented in Table 7 for test waves from 101 deg with the +2.7-m (+8.8-ft) swl and 88 deg with the +2.7-, +3.7-, and +4.1-m (+8.8-, +12.0-, and +13.6-ft) swl's. Maximum wave heights along Camp Ellis Beach were 1.2 and 1.4 m (3.9 and 4.7 ft) for the 101- and 88-deg directions, respectively, with the +2.7-m (+8.8-ft) swl. Significantly less overtopping was observed for the Plan 7 spur structure for test waves for the +2.7-m (+8.8-ft) swl as opposed to that obtained for Plan 6. Maximum wave heights along the beach for test waves from 88 deg with the +3.7-m and +4.1-m (+12.0- and +13.6-ft) swl's were 1.8 and 1.9 m (5.9 and 6.3 ft), respectively.

Wave-induced current patterns and magnitudes for Plan 7 are shown in Photos 90-93 for representative test waves from 101 and 88 deg with the +2.7-, +3.7-, and +4.1-m (+8.8-, +12.0-, and +13.6-ft) swl's. In general, currents in the vicinity moved in a northerly direction. Maximum velocities obtained along the immediate Camp Ellis Beach area were 0.3 m/s (1.0 fps) for 15-sec, 5.5-m (18-ft) test waves from 88 deg with the +3.7-m (+12.0-ft) swl. Current velocities moving northerly, seaward of the spur, were greater than those moving along the shoreline. Typical wave patterns secured for Plan 7 also are shown in Photos 90-93.

General movement of tracer material along the beach for Plan 7 is shown in Photos 94-98 for representative test waves from 101 and 88 deg. For test waves from 101 and 88 deg with the +2.7-m (+8.8-ft) swl, sediment tracer migrated shoreward (Photos 94-96) and did not move north out of the immediate area as it did for existing conditions and the previously tested improvement plans. For extreme storm conditions from 88 deg with the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's, sediment material overwashed the fixed bed model overbank (Photos 97 and 98). Runup was significantly less, however, than that obtained for existing conditions, as shown in Photos 29 and 30. It was noted that sediment tracer was not transported north out of the immediate area of Camp Ellis Beach for this test plan.

Results of wave height tests conducted for Plan 8 are presented in Table 8 for test waves from 101 deg with the +2.7-m (+8.8-ft) swl and 88 deg with the +2.7-, +3.7-, and +4.1-m (+8.8-, +12.0-, and +13.6-ft) swl's. Maximum wave heights along Camp Ellis Beach were 2.29 and 2.26 m (7.5 and 7.4 ft), respectively, for the 101- and 88-deg directions with the +2.7-m (+8.8-ft) swl. The Plan 8 structure resulted in more wave energy along the beach than the Plan 7 structure. Maximum wave heights along the beach for test waves from 88 deg with the 3.7- and 4.1-m (+12.0- and +13.6-ft) swl's were 2.8 and 2.9 m (9.3 and 9.5 ft), respectively.

Wave-induced current patterns and magnitudes for Plan 8 are shown in Photos 99-102 for representative test waves from 101 and 88 deg with the +2.7-, +3,7-, and +4.1-m (+8.8-, +12.0-, and +13.6-ft) swl's. Currents in the vicinity, in general, moved in a northerly direction. Maximum velocities recorded along the immediate Camp Ellis Beach area were 0.24 m/s (0.8 fps) for 13-sec, 5.5-m (18-ft) waves from 88 deg with the +2.7-m (+8.8-ft) swl.

Current velocities moving northerly seaward of the structure were greater than those moving along the shoreline. Typical wave patterns obtained for Plan 8 are also shown in Photos 99-102.

General movement of tracer material along Camp Ellis Beach for Plan 8 is shown in Photos 103-107 for representative test waves from 101 and 88 deg. For the +2.7-m (+8.8-ft) swl, sediment tracer material migrated shoreward (Photos 103-105) and remained in the immediate area. The material was not as stable as it had been for Plan 7, but it did not migrate northerly as it did for most of the previous plans. For severe storm wave conditions with the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's, sediment overwashed the overbank (Photos 106 and 107) with runup similar to that of Plan 7, but significantly less than that obtained for existing conditions.

Results of wave height tests along Camp Ellis Beach with Plan 9 installed are presented in Table 9 for test waves from 101 deg with the 0.0- and 2.7-m (0.0- and +8.8-ft) swl's, test waves from 88 deg with the +2.7-, +3.7-, and +4.1-m (+8.8-, +12.0-, and +13.6-ft) swl's, and test waves from 75 and 56 deg with the +2.7-m (+8.8-ft) swl. For the 0.0-m (0.0-ft) swl, maximum wave heights obtained along the beach (Gages 1-6) were 1.1 m (3.7 ft) for 9-sec, 3.7-m (12-ft) test waves. With the +2.7-m (+8.8-ft) swl, maximum wave heights were 2.5, 2.6, 2.3, and 0.4 m (8.3, 8.4, 7.5, and 1.4 ft) for the 101-, 88-, 75-, and 56-deg directions, respectively. Maximum wave heights along the beach for the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's were 2.8 and 3.3 m (9.3 and 10.8 ft), respectively.

Wave gages were placed in the navigation channel (Gages 13-17), and wave height tests were conducted for Plan 9 and existing conditions for test waves from the various directions. These data are compared in Table 10. For test waves from 101 deg with the 0.0-m (0.0-ft) swl, maximum wave heights were 2.2 m (7.2 ft) in the outer portion of the channel (Gage 17), 0.4 m (1.4 ft) in the mid portion of the channel (Gage 15), and 0.5 m (1.7 ft) in the inner portion of the channel (Gage 13) for Plan 9 versus 2.3, 0.3, and 0.33 m (7.6, 1.0, and 1.1 ft), respectively, for existing conditions. For test waves from all directions with the +2.7-m (+8.8-ft) swl, maximum wave heights for Plan 9 were 3.7 m (12.0 ft) in the outer portion of the channel, 1.9 m (6.1 ft) in the mid portion of the channel, and 1.8 m (5.8 ft) in the inner portion of the channel versus 3.4, 1.3, and 0.4 m (11.2, 4.3, and 1.3 ft) for existing conditions, respectively. The +3.7-m (+12.0-ft) swl yielded maximum wave heights of 3.8 and 4.0 m (12.5 and 13.0 ft) in the outer portion of the channel, 2.1 and 1.9 m (7.0 and 6.1 ft) in the mid portion of the channel, and 2.0 and 0.7 m (6.6 and 2.3 ft) in the inner portion of the channel for Plan 9 and existing conditions, respectively. With the +4.1-m (+13.6-ft) swl, maximum wave heights for Plan 9 and existing conditions, respectively, were 4.2 and 4.3 m (13.8 and 14.2 ft) in the outer portion of the channel, 2.3 and 2.3 m (7.4 and 7.4 ft) in the mid portion of the channel, and 2.4 and 1.0 m (7.9 and 3.5 ft) in the inner portion of the channel. In general, wave heights obtained in the navigation channel (particularly the mid and inner portions) were significantly larger for Plan 9 than for existing conditions.

Wave-induced current patterns and magnitudes with Plan 9 are shown in Photos 108-122 for representative test waves from all four test directions both with and without river flow. For the 101-, 88-, and 75-deg directions, currents adjacent to the beach moved in a northerly direction. The 56-deg direction resulted in weak counterclockwise eddies adjacent to the beach. Maximum velocities obtained along Camp Ellis Beach were 0.6, 0.9, 0.6, and 0.09 m/s (1.9, 2.9, 1.9, and 0.3 fps) for the 101-, 88-, 75-, and 56-deg directions, respectively. The 91 m^3/s (3,200-cfs) river flow had little effect on current patterns along the shoreline. Typical wave patterns obtained for Plan 9 also are shown in Photos 108-122.

The general movement of tracer material along Camp Ellis Beach with Plan 9 installed in the model is shown in Photos 123-136 for representative test waves from the various directions both with and without river flow conditions. For test waves from 101, 88, and 75 deg with the +2.7-m (+8.8-ft) swl, sediment tracer material migrated in a northerly direction with the larger test waves resulting in a faster erosion rate. Severe storm waves from 88 deg with the +3.7-m (+12.0-ft) swl resulted in most material being washed onto the overbank with some migrating north, similar to existing conditions. For test waves from 56 deg, sediment remained in the immediate vicinity of Camp Ellis Beach for the +2.7-m (+8.8-ft) swl. Test results for Plan 9 were very similar to those obtained for existing conditions. Tests conducted with the 91-m^3/s (3,200-cfs) Saco River flow (Photos 133-136) indicated that the river discharge had no impact on sediment movement along the beach.

Historical erosion tests

Sediment tracer tests were conducted for three historical test series, both with and without river flow conditions. Tests involved pre-breakwater conditions of 1866, the original +3.0-m (+10-ft) el breakwater completed in 1873, and the raised +4.6-m (+15-ft) el breakwater completed in 1897. Each of these conditions was subjected to test waves over a cumulative 32-hr period. The shoal was initially subjected to 13-sec, 3.7-m (12-ft) test waves from 101 deg for 5 hr without river flow, followed by 5 hr with river flow conditions. Then 13-sec, 5.5-m (18-ft) test waves from 88 deg were generated for 3 hr without flow and 3 hr with river flow conditions. The shoal formation then was subjected to 11-sec, 4.3-m (14-ft) test waves from 75 deg for 3 hr without flow followed by 3 hr with river flow conditions. Finally, the configuration was subjected again to 13-sec, 3.7-m (12-ft) test waves from 101 deg for 8 hr, the first 4 hr without river flow followed by 4 hr with river flow. All tests were conducted with the +2.7-m (+8.8-ft) swl.

An overall view of pre-breakwater conditions prior to testing is shown in Photo 137. Progression of shoal movement is presented in Photos 138-141. After 5 hr of testing, two small bars formed seaward of the river mouth and Camp Ellis Beach. These configurations progressively increased in size after tests from each direction, and after 22 hr of testing, they joined to form a large bar. The bar continued to grow, and after the 32-hr test series was completed,

it extended across the entire river mouth in a northerly direction and seaward of Camp Ellis Beach. Sediment movement at the river mouth and southern portion of Camp Ellis Beach is shown in Photos 142-145 for the test series. Accretion of the beach occurred for these tests. The progression of sediment tracer movement along the northern portion of Camp Ellis Beach is shown in Photos 146-149. Accretion of the shoreline occurred; however, it was noted that movement of material to the north out of the Camp Ellis Beach area continued throughout the entire test series.

An overall view of the original +3.0-m (+10-ft) el breakwater condition is shown in Photo 150 prior to model testing. Bathymetry was remolded to 1866 conditions and the 32-hr test series was conducted. Progression of sediment movement is shown in Photos 151-154. After 5 hr of testing, a bar formed seaward of Camp Ellis Beach. This bar increased in size after 10 hr of testing, and an additional bar formed adjacent to the breakwater. These bar configurations progressively increased in size, and after 22 hr of testing, they joined, forming one large bar. Material moved over and through the breakwater. The bar continued to grow and extended across the river mouth in a northerly direction seaward of Camp Ellis Beach after the 32-hr test series was completed. Sediment movement at the river mouth and southern portion of the beach (shown in Photos 155-158) indicated accretion occurring in this area throughout the test series. The progression of sediment movement along the northern portion of Camp Ellis Beach is shown in Photos 159-162. Accretion of the shoreline occurred; however, tracer material continued movement to the north out of the Camp Ellis Beach area throughout the test series.

An overall view of the raised +4.6-m (+15-ft) el breakwater condition prior to model testing is shown in Photo 163. Bathymetry was again remolded to 1866 conditions and subjected to the 32-hr test series. Progression of sediment movement is shown in Photos 164-167. After 5 hr of testing, bars formed at the dogleg in the breakwater and seaward of Camp Ellis Beach. A spit also formed extending seaward from Camp Ellis Beach. The bars continued to grow in size and, after 22 hr of testing, joined together. After 27 hr, a bar extended to the shoreline along the northern portion of Camp Ellis Beach. Sediment moved through the breakwater and formed a bar adjacent to the channel side of the structure, but did not extend across the river mouth as it had done for the pre- and original breakwater conditions. The size of the spit extending seaward from Camp Ellis Beach increased with time. Sediment movement at the river mouth and along the southern portion of Camp Ellis Beach is shown in Photos 168-171. The spit mentioned previously is shown in more detail in these photos. The progression of sediment movement along the northern portion of Camp Ellis Beach is shown in Photos 172-175 for the raised breakwater. Accretion of the shoreline occurred, but tracer material continued to move to the north out of the Camp Ellis Beach area throughout the test series.

Discussion of test results

Wave heights obtained for existing conditions indicated rough and turbulent wave conditions along Camp Ellis Beach for storm waves from 101, 88, and 75 deg with the higher swl's (+2.7 to +4.1 m (+8.8 to +13.6 ft)). Wave heights ranging from about 2.4 to 2.7 m (8 to 9 ft) will occur adjacent to the beach during storms with mean high water conditions (el +2.7 m (+8.8 ft)). Increases in water level due to extreme storms will result in wave heights along the beach reaching almost 3.4 m (11 ft). Tests also revealed little wave energy along the shoreline during low water conditions (el 0.0 m (0.0 ft)).

Sediment tracer tests for existing conditions revealed sediment movement to the north for waves from 101, 88, and 75 deg with the +2.7-m (+8.8-ft) swl. Larger test waves moved the material out of the area more quickly than smaller, everyday wave conditions. Extreme storm waves with the +3.7- and +4.1-m (+12.0- and +13.6-ft) swl's resulted in high levels of onshore movement of sediment tracer material onto the model overbank. The model was constructed in cement and could not erode; however, these extreme conditions would probably result in severe shoreline erosion of the Camp Ellis Beach area in the prototype. Test waves from 101, 88, and 75 deg with the 0.0-m (0.0-ft) swl did not move the tracer material out of the immediate vicinity of Camp Ellis Beach, nor did the small test waves from 56 deg for either the 0.0- or +2.7-m (0.0- or the +8.8-ft) swl. Since waves arrive at the site predominantly from 101 through 88 deg and high tides occur daily, net sediment movement in the area is expected to be toward the north. Current patterns obtained for existing conditions also indicated northerly current movement for all test directions.

Results of wave height tests for the roughened breakwater of Plan 1 indicated, in general, a slight but not significant decrease in wave heights along Camp Ellis Beach, as opposed to those obtained for existing conditions. In some cases, waves reflected off the north breakwater were not as apparent for Plan 1; however, maximum wave heights along the beach for the various swl's did not vary significantly. Wave-induced current patterns and magnitudes also were similar for existing conditions and Plan 1. A comparison of sediment tracer patterns for existing conditions and Plan 1 reveals, in general, very similar movement to the north for corresponding test conditions. Test results indicate that Plan 1 roughening of the inner portion of the north breakwater does not appear to have any significant beneficial effect on erosion of the beach.

Test results for the beachfill plans for both the existing (Plan 2) and proposed roughened (Plan 3) breakwaters indicated that sediment tracer material would migrate north and after a time erode to the existing shoreline which indicates erosion would probably occur. The roughened breakwater was not effective in lessening erosion at the site. In light of these test results, it was determined that beachfill plans would be only temporary solutions to the erosion problem at Camp Ellis Beach (i.e., periodic nourishment would be necessary).

Test results for the 152,920-cu-m (200,000-cu-yd), Plan 4 submerged berm configuration revealed that, initially the berm appeared to diminish the wave energy reaching the beach, which resulted in a decrease in the rate of erosion along Camp Ellis Beach, as opposed to that for existing conditions. The berm material migrated toward, and actually fed, the beach. After continued exposure to wave action, however, the berm eroded to a point where it provided no wave protection and berm material along the beach eventually moved north. Thus, the berm should be considered only a temporary solution to erosion at Camp Ellis Beach.

Test results for the 76,460-cu-m (100,000-cu-yd) Plan 5 submerged berm configuration revealed that the berm did not significantly diminish wave energy reaching the shoreline. The rate of erosion along Camp Ellis Beach was similar to that obtained for existing conditions. The berm material itself, however, migrated toward, and fed, the beach. Additional wave exposure resulted in the material along the beach moving north, and like Plan 4, the Plan 5 submerged berm should be considered only a temporary solution to erosion at Camp Ellis Beach.

Results of wave height tests for the +3.0-m (+10-ft) crest el, 914-m-long (3,000-ft-long) spur of Plan 6 indicated reduced wave heights along Camp Ellis Beach when compared to those measured for existing conditions at the +2.7-m (+8.8-ft) tide conditions (1.5 versus 2.7 m (4.8 versus 8.9 ft)). A comparison of sediment tracer patterns indicated that Plan 6 would significantly reduce the rate of erosion of the beach; however, with continued exposure to wave action, sediment along the beach would eventually erode, moving north. By raising the crest el of the spur to +4.6 m (+15 ft) (Plan 7), wave heights were reduced to 1.2 m (3.9 ft) for similar conditions with the +2.7-m (+8.8-ft) swl. Current magnitudes adjacent to Camp Ellis Beach for Plan 7 were 0.3 m/s (1.0 fps) as opposed to 0.9 m/s (3.1 fps) for existing conditions. Sediment tracer patterns for Plan 7 indicated that sediment will not move out of the immediate vicinity of Camp Ellis Beach for storm waves during normal high water tidal conditions. Runup onto the overbank was reduced significantly with Plan 7 (versus existing conditions) for extreme wave and tide conditions; therefore, the plan should result in less damage to the shoreline for these extreme occurrences. The reduction in length of the spur from 914 to 457 m (3,000 to 1,500 ft) (Plan 8) resulted in wave heights along the beach increasing to 2.3 m (7.5 ft) for +2.7-m (+8.8-ft) tide conditions; however, due to wave diffraction around the spur head, waves tended to approach the beach from a more northerly direction. Sediment tracer tests for Plan 8 indicated that material along Camp Ellis Beach in the lee of the spur will not be as stable as for Plan 7, but it will not move out of the immediate area. Runup and current patterns and magnitudes for Plan 8 were similar to those obtained for Plan 7. The longer Plan 7 structure should provide wave and shoreline protection for a longer reach of the beach (to the north) than Plan 8.

Results of wave height tests along the beach with the north breakwater removed (Plan 9) revealed that maximum wave heights were slightly, but not significantly, less than those obtained for existing conditions. However,

considering all test conditions, wave heights along Camp Ellis Beach were comparable to those obtained for existing conditions. Wave height data secured in the navigation channel for Plan 9 revealed significant increases in wave heights, as opposed to existing conditions, which will result in hazardous navigation conditions and possible damage to vessels and coastal facilities inside the river mouth.

Sediment tracer tests for Plan 9 revealed sediment movement to the north for test waves from 101, 88, and 75 deg with the +2.7-m (+8.8-ft) swl. Extreme storm waves with the +3.7-m (+12.0-ft) swl washed sediment onto the overbank, and test waves from 56 deg resulted in sediment material remaining in the immediate vicinity of Camp Ellis Beach. A comparison of these results with existing conditions reveals very similar sediment patterns, except the Plan 9 condition appeared to erode at a slightly increased rate for the smaller (1.8 to 2.4 m (6 to 8 ft)) wave conditions from 101, 88, and 75 deg. Results also indicated that the 91 m^3/s (3,200-cfs) river discharge for Plan 9 had no impact on sediment movement along Camp Ellis Beach. Wave-induced current patterns and magnitudes for Plan 9 also were similar to those obtained for existing conditions. This test series indicates the north breakwater's impact on hydrodynamic conditions is only minor and results in insignificant changes in the northerly sediment transport which exists at Camp Ellis Beach.

Sediment tracer tests conducted for the pre-breakwater conditions of 1866 indicated that the shoal at the river mouth tended to meander forming offshore bars and building the beach for the storm wave conditions tested. The shoal at the river mouth at this time was characteristic of an ebb tidal delta. Mean river flow used during model testing appeared to be of little benefit in keeping the river channel open since a bar formed across the entrance. In the prototype, tidal flows through the entrance would likely prevent it from closing but not necessarily keep the entrance navigable. However, these flows were not reproduced in the model. Tests conducted for this study compare relative changes for the various alternatives based on the hydrodynamic conditions tested. The original +3.0-m (+10-ft) el breakwater completed in 1873 had little impact on bar formations. For the conditions tested, sediment material moved over and through the structure and resulted in a very similar bar formation across the entrance as pre-breakwater conditions. Historical records indicate channel shoaling during this period due to material penetrating over the original breakwater (USAED, New England 1992), which was the reason the structure was raised. The raised +4.6-m (+15-ft) el breakwater completed in 1897 was effective in reducing the amount of shoaling in the navigation channel. Some material moved through the structure and formed a bar adjacent to the channel side of the breakwater, but most the sediment in the shoal formed bars north of the raised structure seaward of Camp Ellis Beach. It was noted that, for all the conditions tested, sediment constantly moved northerly out of the Camp Ellis Beach area. None of the test conditions resulted in a reversal of sediment movement from north to south back toward Camp Ellis Beach. Test results suggest that regardless of the condition of the north breakwater, without natural nourishment or replenishment, Camp Ellis Beach will erode with net sediment transport to the north.

It was noted in the model investigation that wave-induced currents and sediment migration were toward the north, for test waves from 101, 88, and 75 deg, both with and without the north breakwater installed at the Saco River mouth. The small test waves generated from 56 deg resulted in weak eddying currents along the beach with no sediment movement to the north or south. Hindcast data from the wave exposure window (56 to 101 deg) at Camp Ellis Beach indicate that only about 10 percent of the wave occurrences (from the 1956-1975 period of record) approach from the 56 deg (45 deg deepwater) direction. Therefore, net sediment movement in the Camp Ellis Beach area should be northerly. The model indicated no southerly transport; however, had larger waves from 56 deg been supported by the hindcast and generated in the model at a deeper, storm-induced water level, a southerly migration of sediment may have resulted as hypothesized in USAEWES (1991) and USAED, New England (1992). Based on hindcast conditions used to force the model, only northerly transport was observed.

5 Conclusions

Based on results of the coastal hydraulic model investigation reported herein, it is concluded that:

a. During periods of storm wave activity and high tide conditions (+2.7 m (+8.8 ft)) at Camp Ellis Beach, wave heights ranging from 2.4 to 2.7 m (8 to 9 ft) will occur adjacent to the beach for existing conditions. For extreme storm events with tides in excess of +4.1 m (+13 ft), wave heights adjacent to the beach will reach approximately 3.4 m (11 ft). Little wave energy appears to reach the area, however, for low tide conditions (0.0 m (0.0 ft)).

b. Sediment tracer tests for existing conditions indicated that erosion would occur along Camp Ellis Beach for the higher tide levels with net movement of sediment in a general northerly direction. Larger wave conditions would result in an increased rate of erosion. For the lower tide levels, however, test waves would not move sediment out of the immediate vicinity of Camp Ellis Beach.

c. The roughened breakwater plan (Plan 1) would not significantly reduce wave heights, alter current patterns and magnitudes, or prevent erosion in the vicinity of Camp Ellis Beach. Test results were very similar to those obtained for existing conditions.

d. For the beachfill plans with the existing (Plan 2) and roughened (Plan 3) breakwaters, sediment would move north, and beachfills would eventually erode to the existing shoreline. Beachfill plans would only be temporary solutions to the erosion problems at Camp Ellis Beach (i.e., requiring periodic renourishment).

e. The 152,920-cu-m (200,000-cu-yd) Plan 4 submerged berm configuration initially would result in reduced wave energy reaching the beach and a slightly reduced rate of erosion along Camp Ellis Beach. The 76,460-cu-m (100,000-cu-yd) Plan 5 submerged berm configuration provided minimal wave protection and would initially result in erosion along the beach similar to existing conditions. Sediment from both berm configurations would migrate toward, and feed, the beach. After continued exposure to wave action, the berms would erode to a point

where they provide little or no protection and sediment will migrate north; thus, the submerged berms would only be temporary solutions to the erosion problem at Camp Ellis Beach.

f. Of the spur jetty plans tested, the +4.6-m (+15-ft) crest elevation, 914-m-long (3,000-ft-long) structure of Plan 7 was most effective in significantly reducing wave heights along Camp Ellis Beach. Both Plan 7 and the +4.6-m (+15-ft) crest elevation, 457-m-long (1,500-ft-long) structure of Plan 8 would be effective in preventing erosion of the beach. For both plans, sediment would remain in the immediate vicinity and not migrate in a northerly direction. The longer Plan 7 spur jetty would provide a more stable shoreline and protect a longer reach than the Plan 8 structure.

g. Removal of the north breakwater (Plan 9) would not significantly reduce wave heights, alter current patterns and magnitudes, or decrease the erosion rate along Camp Ellis Beach. Since the north breakwater's impact on hydrodynamics off Camp Ellis Beach is minimal, the presence of the structure should result in insignificant changes in the northerly migration of sediment along the beach. Breakwater removal would, however, significantly increase wave heights in the navigation channel. Test results also indicate that the 91-m^3/s (3,200-cfs) Saco River discharge would have no impact on the erosion rate along the beach.

h. Pre-breakwater conditions of 1866 indicated that the ebb shoal at the river mouth would meander, forming offshore bars and building the beach. These bars would severely hamper, if not stop, navigation. The original +3.0-m (+10-ft) el breakwater constructed in 1873 resulted in similar shoaling patterns, since sediment moved over and through the structure. The raised +4.6-m (+15-ft) el breakwater, completed in 1897, reduced navigation channel shoaling and resulted in offshore bar formations north of the structure and seaward of Camp Ellis Beach. All conditions tested with the historical alternatives resulted in sediment constantly moving north out of the Camp Ellis Beach area, suggesting eventual erosion without nourishment or replenishment of the Camp Ellis Beach.

References

Berkhoff, J. C. W. (1973). "Computation of combined refraction-diffraction." *Proceedings of the 13th International Conference on Coastal Engineering, American Society of Civil Engineers*, Vol I, 471-90.

Booji, N. (1981). "Gravity waves on water with non-uniform depth and current," Ph.D. diss., Technical University of Delft, The Netherlands.

Bottin, R. R., Jr., and Chatham, C. E., Jr. (1975). "Design for wave protection, flood control, and prevention of shoaling, Cattaraugus Creek Harbor, New York; Hydraulic model investigation," Technical Report H-75-18, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Brasfeild, C. W., and Ball, J. W. (1967). "Expansion of Santa Barbara Harbor, California; Hydraulic model investigation," Technical Report 2-805, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Chatham, C. E., Jr., Davidson, D. D., and Whalin, R. W. (1973). "Study of beach widening by the perched beach concept, Santa Monica Bay, California; Hydraulic model investigation," Technical Report H-73-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Corson, W. D., et al. (1981). "Wave information studies of U.S. Coastlines; Atlantic Coast hindcast, deepwater, significant wave information," WIS Report 2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dai, Y. B., and Jackson, R. A. (1966). "Design for rubble-mound breakwaters, Dana Point Harbor, California; Hydraulic model investigation," Technical Report 2-725, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dally, W. R., et al. (1985). "Wave height variations across beaches of arbitrary profile," *Journal of Geophysical Research* 90, 11,917-27.

Dalrymple, R. A. (1988). "A model for the refraction of water waves," *Journal of Waterways, Port, Coastal and Ocean Engineering*, American Society of Civil Engineers, 114.

Dalrymple, R. A. (1991). "REFRACT: A refraction program for water waves, V2.0," Report CACR-91-09, Center for Applied Coastal Research, University of Delaware, Civil Engineering Department.

Dalrymple, R. A., et al. (1984a). "Wave diffraction due to areas of energy dissipation," *Journal of Waterway, Port, Coastal and Ocean Engineering*, American Society of Civil Engineers, 110, 67-79.

__________. (1984b). "Wave propagation in the vicinity of islands." *Proceedings, 16th Offshore Technical Conference*, Paper No. 4675.

Giles, M. L., and Chatham, C. E., Jr. (1974). "Remedial plans for prevention of harbor shoaling, Port Orford, Oregon; Hydraulic model investigation," Technical Report H-74-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Gilhousen, D. B., et al. (1986). "Climatic summaries for NDBC data buoys," National Data Buoy Center, National Space and Technology Center, MS.

Hedges, T. S. (1976). "An empirical modification to linear wave theory," Institute of Civil Engineering, London, England, 575-79.

Hubertz, J. M., and Curtis, W. R. (1993). "Wind wave and water level hindcast results for the Blizzard of 1978 and the Halloween Storm of 1991 for Coastal New England," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, prepared for U.S. Army Engineer Division, New England.

Hubertz, J. M., Brooks, R. M., Brandon, W. A., and Tracy, B. A. (1993.) "Hindcast wave information for the U.S. Atlantic Coast, 1956-1975," WIS Report 30, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Hunt, J. N. (1979). "Direct solution of wave dispersion equation," *Journal of Waterway, Port, Coastal and Ocean Engineering*, American Society of Civil Engineers, 105, 457-59.

Jensen, R. E. (1983). "Wave information studies of U.S. Coastlines; Methodology for the calculation of a shallow-water wave climate," WIS Report 8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Kirby, J. T. (1984). "A note on linear surface wave-current interaction," *Journal of Geophysical Research* 89, 745-47.

__________. (1986). "Higher-order approximations in the parabolic equation method for water waves," *Journal of Geophysical Research* 91, 933-52.

Kirby, J. T., and Dalrymple, R. A. (1983a). "A parabolic equation for combined refraction-diffraction of stokes waves by mildly varying topography," *Journal of Fluid Mechanics*, 136, 543-66.

_________. (1983b). "The propagation of weakly nonlinear waves in the presence of varying depth and currents." *Proceedings, 20th Congress IAHR, Moscow.*

_________. (1986a). "Modelling waves in surf zones and around islands," *Journal of Waterway, Port, Coastal and Ocean Engineering*, American Society of Civil Engineers 112, 78-93.

_________. (1986b). "An approximate model for nonlinear dispersion in monochromatic wave propagation models," *Coastal Engineering* 9, 545-61.

Le Mehaute, B. (1965). "Wave absorbers in harbors," Contract Report No. 2-122, National Engineering Science Co., Pasadena, CA, for U.S. Army Engineer Waterways Experiment Station under Contract No. DA-22-079-CIVENG-64-81.

Liu, P. L. F., and Tsay, T. K. (1984). "On weak reflection of water waves," *Journal of Fluid Mechanics* 131, 59-71.

Noda, E. K. (1972). "Equilibrium beach profile scale-model relationship," *Journal, Waterways, Harbors, and Coastal Engineering Division*, American Society of Civil Engineers 98, (WW4), 511-28.

Shore protection manual. (1984). 4th ed., 2 Vol, U.S. Army Engineer Waterways Experiment Station, U.S. Government Printing Office, Washington, DC.

Stevens, J. C., et al. (1942). "Hydraulic models," *Manuals of Engineering Practice No. 25*, American Society of Civil Engineers, New York.

U.S. Army Engineer Division, New England. (1967). Small navigation project, Saco River, Saco-Biddeford, Maine," Detailed Project Report, Waltham, MA.

_________. (1978). "Maintenance dredging, Saco River, Biddeford/Saco, Maine," Draft Environmental Impact Statement, Waltham, MA.

_________. (1992). "Camp Ellis Beach, Saco, Maine, beach erosion study," Section 111 Reconnaissance Report, Waltham, MA.

U.S. Army Engineer Waterways Experiment Station. (1991). "Assessment of coastal processes in Saco Bay, Maine, with emphasis on Camp Ellis Beach," Memorandum, Coastal Engineering Research Center, Vicksburg, MS.

Table 1
Estimated Magnitude of Deepwater Waves (Sea and Swell) in Saco Bay Approaching Camp Ellis Beach from the Directions Indicated

Wave Height, ft	Occurrences[1] per Wave Period, sec							
	3-5	5-7	7-9	9-11	11-13	13-15	15-17	Total
45 Degrees								
0 - 3.3	669	38						707
3.3 - 6.6	274	131						405
6.6 - 9.8		80						80
9.8 - 13.1		3						3
Total	943	252						1,195
67.5 Degrees								
0 - 3.3	581	161	24					766
3.3 - 6.6	180	307	45	5				537
6.6 - 9.8		70	31	14				115
9.8 - 13.1		3	12					15
13.1 - 16.4				1				1
Total	761	541	112	20				1,434
90 Degrees								
0 - 3.3	715	326	42	1				1,084

(Continued)

[1] Occurrences compiled for period 1956-1975. Each occurrence represents a 3-hr duration.

Table 1 (Concluded)

Wave Height, ft	Occurrences[1] per Wave Period, sec							
	3-5	5-7	7-9	9-11	11-13	13-15	15-17	Total
90 Degrees								
3.3 - 6.6	102	633	218	20	1			974
6.6 - 9.8		88	192	54	3			337
9.8 - 13.1		1	51	41	8			101
13.1 - 16.4			1	14	11			26
16.4 - 19.7					5	4		9
19.7 - 23.0					1			1
Total	817	1,048	504	130	29	4		2,532
103 Degrees								
0 - 3.3	724	539	831	1,149	653	48		3,944
3.3 - 6.6	80	791	453	342	160	18		1,844
6.6 - 9.8		6	295	140	33	4	6	574
9.8 - 13.1			58	99	22	1		180
13.1 - 16.4			1	29	30	2		62
16.4 - 19.7					12	5		17
19.7 - 23.0					1	1		2
Total	804	1,426	1,638	1,759	911	79	6	6,623

Table 2
Summary of Refraction/Diffraction and Shoaling Analysis for Camp Ellis Beach

Wave Period sec	Shallow-Water Azimuth, deg	Wave-Height[1] Adjustment Factor
Northeast, 45 deg		
5	56.5	0.368
7	55.9	0.316
East-Northeast, 67.5 deg		
5	69.0	0.800
7	71.9	0.700
9	75.4	0.616
11	81.9	0.838
East, 90 deg		
5	87.4	0.883
7	86.9	0.780
9	90.0	0.740
11	90.4	1.000
13	86.7	0.788
15	86.4	0.746
Approximately East-southeast, 103 deg		
5	101.4	0.860
7	101.7	0.750
9	100.3	0.663
11	101.2	0.592
13	99.9	0.488
15	100.3	0.616
17	101.4	0.556

[1] Values at approximate location of wave generator in model.

Table 3
Estimated Magnitude of Shallow-Water Waves (Sea and Swell) Approaching Camp Ellis Beach from the Directions Indicated

Wave Height, ft	Occurrences[1] per Wave Period, sec							
	3-5	5-7	7-9	9-11	11-13	13-15	15-17	Total
45 Degrees								
0 - 2	669	38						707
2 - 4	274	214						488
Total	943	252						1,195
67.5 Degrees								
0 - 2			24					24
2 - 4	581	161	45					787
4 - 6	180	307	31	5				523
6 - 8		70	12					82
8 - 10		3		14				17
10 - 12								
12 - 14				1				1
Total	761	541	112	20				1,434
90 Degrees								
0 - 2								

(Continued)

[1] Occurrences compiled for period 1956-1975. Each occurrence represents a 3-hr duration.

Table 3 (Concluded)

Wave Height, ft	Occurrences[1] per Wave Period, sec						
	3-5	5-7	7-9	9-11	11-13	13-15	15-17	Total
90 Degrees								
2 - 4	715	326	42	1				1,084
4 - 6	102	633	218		1			954
6 - 8		88	192	20				300
8 - 10		1	51	54	3			109
10 - 12			1		8			9
12 - 14				41	11			52
14 - 16					5	4		9
16 - 18				14	1			15
Total	817	1,048	504	130	29	4		2,532
103 Degrees								
0 - 2				1,149	653			1,802
2 - 4	724	539	831	342	160	48		2,644
4 - 6	80	791	453	140	33	18	6	1,521
6 - 8		96	295	99	52	5		547
8 - 10			58	29	12	2		101
10 - 12			1		1	5		7
12 - 14						1		1
Total	804	1,426	1,638	1,759	911	79	6	6,623

Table 4
Wave Heights for Existing Conditions

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +0.0 ft														
101	5	6	0.4	0.2	0.4	0.4	0.8	0.9	1.3	1.4	2.0	2.3	1.6	0.9
	7	8	0.8	0.8	1.1	1.8	1.9	1.9	2.3	2.4	5.0	2.9	2.9	1.3
	9	4	0.6	0.4	0.7	0.9	1.5	1.1	1.4	2.0	2.6	1.9	1.9	0.9
		8	2.1	1.2	1.6	3.0	3.3	2.6	3.3	3.0	6.2	3.5	4.0	1.5
		12	2.8	2.6	3.0	4.9	4.5	3.3	4.2	3.8	6.0	5.0	5.7	3.4
	11	6	1.3	0.9	0.9	1.8	2.1	2.0	2.9	2.6	3.5	2.7	2.3	1.2
		10	2.5	1.4	1.5	3.0	4.0	2.7	3.6	3.5	5.0	4.1	4.8	2.5
	13	4	0.6	0.3	0.5	0.5	1.0	0.8	1.3	1.7	2.1	1.5	1.5	0.8
		8	1.4	1.0	1.1	1.9	2.7	2.3	3.6	2.9	5.0	3.9	3.6	1.9
		12	2.2	1.3	2.0	3.0	3.6	2.6	3.7	3.3	5.4	4.5	4.9	3.0
	15	4	0.6	0.4	0.6	0.7	1.1	0.9	1.3	1.7	1.9	1.3	1.6	0.9
		8	1.5	0.8	1.2	2.1	2.4	1.9	2.9	2.7	4.3	3.0	3.5	1.9
		14	2.9	1.9	2.0	3.1	3.4	2.6	3.5	3.2	5.1	4.8	5.3	3.2
	17	6	0.9	0.6	1.0	1.2	1.9	1.4	3.2	2.1	3.1	2.4	2.6	1.7
88	5	6	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	1.3	1.6	0.7	0.3
	7	6	0.1	0.1	0.1	0.1	0.6	0.2	0.5	0.5	1.9	2.2	1.1	0.5

(Sheet 1 of 5)

Table 4 (Continued)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +0.0 ft (Continued)														
88	7	10	0.3	0.1	0.2	0.8	1.8	0.9	1.3	1.6	4.3	3.7	3.3	1.3
	9	4	0.1	0.1	0.1	0.4	0.7	0.5	1.0	1.3	1.8	1.9	1.4	0.9
		8	0.4	0.2	0.7	1.5	2.5	1.5	1.7	1.9	3.5	3.6	2.7	1.6
		12	1.1	0.9	1.3	2.0	3.0	2.2	2.4	2.6	5.2	4.4	4.2	2.5
	11	6	0.6	0.7	0.6	0.7	1.3	0.9	1.7	2.0	2.9	2.5	2.2	1.5
		10	1.3	1.2	1.1	2.1	3.0	2.2	2.7	2.7	4.4	4.4	5.0	2.8
		14	1.4	1.7	1.3	2.2	3.2	2.2	3.1	2.9	5.1	4.7	5.3	3.4
		18	2.4	2.0	2.0	4.2	3.5	2.8	3.8	3.4	5.6	5.2	4.7	3.6
	13	6	0.6	0.7	0.6	1.0	1.4	1.1	1.8	2.1	2.8	3.1	2.3	1.8
		10	1.4	1.1	1.2	2.0	2.6	1.8	2.8	2.8	4.5	5.7	4.7	2.8
		14	1.4	1.4	1.0	2.3	2.6	2.1	2.9	2.7	4.5	4.4	5.1	3.1
		18	2.0	2.3	1.9	2.7	3.1	3.0	3.4	3.3	5.6	5.1	4.7	3.8
	15	16	1.9	1.3	1.4	3.1	2.4	2.2	2.8	2.8	4.8	4.1	4.6	3.3
75	5	6	0.2	0.1	<0.1	<0.1	0.5	0.3	0.7	0.9	1.3	1.2	1.5	0.9
	7	6	0.1	<0.1	<0.1	0.2	0.6	0.2	0.7	0.8	1.8	1.9	2.1	0.8
		10	0.3	0.1	<0.1	<0.1	1.0	0.6	1.1	1.9	3.3	3.8	2.6	1.3

(Sheet 2 of 5)

Table 4 (Continued)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +0.0 ft (Continued)														
75	9	4	0.2	0.1	<0.1	<0.1	0.5	0.3	0.8	0.9	1.3	1.3	1.6	1.0
		8	0.7	0.2	0.1	0.5	1.4	0.9	1.7	2.3	3.2	3.7	3.4	2.1
	11	6	0.7	0.3	0.1	0.4	1.0	0.7	1.5	1.7	2.0	2.1	2.7	2.0
		10	0.9	0.4	0.1	0.9	1.6	1.1	2.2	2.5	3.4	4.1	3.9	2.5
		14	1.1	1.3	0.8	1.8	2.1	1.5	2.5	3.0	3.9	4.6	5.0	2.6
56	5	4	<0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.4	0.4	1.6	1.0	0.6
	7	4	0.1	0.1	0.1	0.3	0.2	0.2	0.3	0.4	0.7	1.4	1.3	0.9
swl = +8.8 ft														
101	5	6	2.1	2.4	2.8	2.7	2.5	2.2	2.4	1.8	2.8	2.6	2.6	2.6
	7	8	5.6	3.9	5.2	3.7	4.8	4.7	4.6	3.8	4.2	4.6	3.9	3.6
	9	4	2.8	2.3	3.1	3.1	2.1	2.6	3.2	2.7	3.3	3.0	2.1	2.6
		8	6.0	4.2	6.2	4.8	4.8	4.1	4.7	4.9	4.2	5.8	5.3	3.1
		12	7.3	7.0	7.4	6.2	7.3	5.8	6.1	5.7	5.2	7.9	6.3	6.7
	11	6	4.9	3.9	4.6	4.5	3.6	3.8	3.5	3.3	3.4	3.5	4.3	3.2
		10	8.1	7.6	7.6	7.6	7.4	6.4	6.0	5.8	5.7	7.4	6.4	5.1
	13	4	3.0	2.2	2.6	3.2	3.1	3.4	2.5	2.1	2.6	2.4	2.2	1.9

(Sheet 3 of 5)

Table 4 (Continued)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft (Continued)														
101	13	8	6.8	6.1	6.6	6.0	6.2	5.9	6.1	5.3	5.5	5.0	5.7	4.2
		12	8.3	8.9	7.3	8.3	7.8	7.2	7.0	6.1	5.3	8.9	7.8	6.7
	15	4	3.1	2.5	3.0	2.5	2.9	3.2	2.5	2.4	3.1	2.6	2.1	2.4
		8	7.4	5.7	6.7	6.0	5.8	5.5	5.3	5.0	5.3	5.1	5.6	4.0
		14	7.9	8.2	7.5	7.1	8.2	7.1	6.7	6.9	6.7	8.8	7.6	7.5
	17	6	5.2	4.1	5.4	4.2	4.2	3.8	3.6	3.9	4.4	3.0	3.8	3.6
88	5	6	1.0	1.4	0.9	1.3	1.6	1.5	2.1	2.0	2.2	2.9	1.8	1.7
	7	6	1.7	2.0	1.9	2.1	1.6	1.9	2.2	2.2	2.5	3.2	2.5	2.6
		10	3.8	3.9	3.0	2.7	3.9	3.8	3.3	4.4	6.1	4.1	4.4	4.3
	9	4	1.5	2.0	1.7	2.3	1.7	1.8	1.8	2.3	2.7	2.4	1.9	2.1
		8	3.1	3.5	2.6	3.5	3.3	3.1	3.1	3.5	3.7	3.9	3.8	3.7
		12	5.1	5.0	4.2	5.2	6.4	6.1	5.0	5.2	7.6	5.6	4.8	4.9
	11	6	2.8	3.3	2.6	3.4	3.4	3.3	4.6	4.3	3.8	3.2	3.2	4.3
		10	5.5	5.4	4.1	5.4	6.1	5.2	4.9	5.2	6.1	5.5	5.4	6.3
		14	6.9	6.9	5.5	6.7	7.8	6.7	6.8	6.4	9.1	7.2	7.1	7.1
		18	6.9	7.0	7.0	7.3	8.9	7.7	7.9	7.1	9.2	8.8	6.8	8.6

Table 4 (Concluded)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft (Continued)														
88	13	6	3.3	4.0	3.7	4.5	4.0	3.9	4.0	4.2	4.3	3.8	3.2	3.5
		10	6.1	6.4	5.6	6.2	6.9	6.4	6.4	5.2	5.9	5.1	5.9	6.5
		14	7.7	7.2	6.8	6.5	8.6	7.4	7.3	6.8	9.5	8.5	8.1	8.5
		18	7.2	7.5	7.5	7.1	8.7	7.5	7.3	6.8	9.9	8.3	8.4	9.0
	15	16	7.7	7.3	6.9	7.0	8.7	7.1	7.1	6.2	10.5	8.4	8.6	9.5
75	5	6	2.1	3.5	2.0	2.2	2.7	2.5	2.4	2.7	2.9	2.2	3.3	3.0
	7	6	2.6	4.7	3.0	2.6	2.7	2.6	2.3	2.6	2.8	2.5	4.4	3.5
		10	4.9	5.6	3.2	4.5	5.3	5.0	4.6	3.4	5.6	4.8	4.5	4.8
	9	4	2.7	3.6	2.2	2.1	2.4	2.1	1.7	2.2	2.0	2.4	3.1	2.8
		8	4.2	5.1	3.2	4.2	4.5	3.8	3.5	3.2	3.9	3.8	4.6	4.7
	11	6	3.7	4.2	3.2	3.5	4.4	3.2	2.9	2.4	3.1	3.3	3.6	3.0
		10	6.7	6.4	5.2	5.4	6.7	5.0	4.7	5.2	5.8	4.5	6.0	6.9
		14	6.9	6.6	6.1	6.6	7.9	6.4	6.5	7.0	7.4	5.7	7.8	7.6
56	5	4	1.8	1.6	1.8	1.6	1.7	1.9	1.8	1.3	1.0	1.4	1.9	1.5
	7	4	1.5	1.7	2.6	1.6	1.8	2.0	2.5	1.5	1.8	1.6	2.8	2.2
swl = +12.0 ft														
88	15	18	7.6	8.2	7.1	8.2	8.7	7.5	9.0	7.9	11.6	10.5	7.4	11.0
swl = +13.6 ft														
88	13	20	8.5	9.6	8.9	10.8	10.1	9.9	9.8	10.6	13.3	11.5	9.5	11.3

(Sheet 5 of 5)

Table 5
Wave Heights for Plan 1

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +0.0 ft														
101	5	6	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.2	1.5	1.6	1.0	0.2
	7	8	0.3	0.1	0.2	0.5	2.6	1.2	1.7	2.0	4.9	2.7	2.5	0.9
	9	4	0.2	0.1	0.1	0.3	1.5	1.0	1.2	1.9	2.6	1.8	1.5	0.8
		8	1.6	0.6	1.7	3.0	3.8	2.6	3.0	3.1	6.7	3.4	3.6	1.4
		12	3.1	1.4	2.4	3.4	5.4	3.1	3.7	3.4	5.8	4.7	5.1	2.6
	11	6	1.0	0.3	0.7	0.4	2.1	1.5	2.7	2.6	3.6	3.0	2.4	1.3
		10	1.9	0.6	1.4	1.4	4.3	2.9	3.6	3.2	4.9	4.2	4.9	2.5
	13	4	0.2	0.1	0.3	0.1	0.5	0.6	1.4	1.7	2.1	1.5	1.5	1.2
		8	1.0	0.3	0.8	0.5	2.6	1.8	3.2	2.8	5.2	3.7	3.8	2.0
		12	1.9	0.8	1.6	2.1	3.2	2.7	3.4	3.1	5.1	3.9	5.0	3.0
	15	4	0.5	0.4	0.5	0.3	0.7	0.8	1.4	1.8	2.1	1.4	1.6	0.9
		8	1.3	0.9	1.2	1.3	2.2	1.9	3.1	2.6	4.4	3.2	3.2	2.0
		14	2.6	1.6	1.7	2.9	3.0	2.5	3.6	3.3	5.6	4.5	5.3	3.0
	17	6	1.1	0.6	1.1	1.6	1.5	1.5	2.4	2.3	3.5	2.3	2.5	1.6
88	5	6	0.1	0.1	0.1	0.2	0.2	0.2	0.6	0.6	1.7	2.1	1.2	0.6
	7	6	0.3	0.1	0.3	0.6	0.8	0.5	1.0	1.1	2.5	2.5	1.6	0.9

(Sheet 1 of 5)

Table 5 (Continued)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +0.0 ft (Continued)														
88	7	10	0.6	0.2	0.8	1.2	1.8	1.1	1.7	2.0	4.6	3.3	4.1	1.5
	9	4	0.3	0.3	0.3	0.5	0.7	0.5	1.0	1.4	1.9	2.0	1.4	1.0
		8	1.0	0.6	0.9	1.9	2.1	1.6	2.3	2.3	3.5	3.6	3.7	1.7
		12	1.5	1.0	1.3	2.7	2.9	2.5	2.9	2.6	5.2	4.8	4.8	3.2
	11	6	0.7	0.6	0.6	1.0	1.1	1.0	1.6	1.9	3.0	2.5	2.1	1.5
		10	1.4	1.2	1.0	1.8	2.6	1.9	2.7	2.5	4.2	4.5	5.1	2.7
		14	1.5	1.8	1.7	2.5	2.9	2.5	3.2	2.9	5.2	4.3	5.0	3.5
		18	2.0	2.2	1.8	3.4	3.7	3.1	4.0	3.7	5.6	5.4	4.8	3.9
	13	6	0.6	0.8	0.7	0.9	1.4	1.2	2.0	2.2	3.2	3.3	2.1	2.2
		10	1.5	1.4	1.2	1.7	2.4	1.9	2.6	2.5	4.2	4.3	4.7	2.9
		14	1.5	1.6	1.2	2.3	2.7	2.1	2.9	2.6	4.6	4.3	5.0	3.2
		18	2.4	2.4	1.8	3.0	3.9	3.0	3.5	3.3	5.3	5.1	4.5	3.4
	15	16	2.1	1.7	1.5	2.6	2.9	2.3	2.9	2.7	5.1	4.0	4.8	3.2
75	5	6	0.1	0.2	0.1	0.1	0.3	0.3	0.8	0.9	1.8	1.7	2.3	1.2
	7	6	0.3	0.3	0.1	0.3	0.7	0.5	1.2	1.2	1.8	1.9	2.2	1.1
		10	0.6	0.6	0.2	0.6	1.1	0.8	1.8	2.1	3.4	3.8	3.0	1.8
	9	4	0.3	0.2	0.1	0.2	0.4	0.4	0.4	0.9	1.0	1.3	1.9	1.2

(Sheet 2 of 5)

Table 5 (Continued)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +0.0 ft (Continued)														
75	9	8	0.8	0.6	0.3	0.8	1.5	1.0	1.7	2.3	3.4	3.0	3.9	2.2
	11	6	0.7	0.5	0.2	0.6	0.8	0.6	1.4	1.7	2.3	1.8	2.6	2.1
		10	0.9	0.9	0.5	1.4	1.7	1.1	2.1	2.5	3.7	3.8	4.1	2.5
		14	1.2	1.3	0.8	1.7	2.1	1.4	2.4	2.8	3.7	4.3	4.8	2.9
56	5	4	0.1	<0.1	<0.1	0.1	0.2	0.1	0.2	0.4	0.5	1.7	1.0	0.7
	7	4	0.1	0.1	<0.1	0.5	0.2	0.2	0.3	0.4	0.6	1.3	1.3	1.0
swl = +8.8 ft														
101	5	6	1.3	2.0	2.4	2.0	2.2	1.9	2.3	1.6	2.4	2.4	2.4	2.7
	7	8	4.6	3.5	4.6	3.9	3.6	4.0	4.3	3.8	4.6	4.9	3.3	3.2
	9	4	2.7	2.7	3.0	2.9	2.1	2.4	3.0	2.7	3.3	2.7	2.6	2.1
		8	5.4	4.0	5.2	4.4	3.9	4.2	5.1	4.2	4.0	5.6	4.1	3.4
		12	6.4	6.4	6.6	5.5	6.1	5.4	5.9	5.6	5.5	7.9	6.7	5.8
	11	6	4.6	3.5	4.2	4.2	3.6	4.2	3.5	3.2	3.5	3.3	4.1	2.7
		10	7.5	6.7	6.8	7.0	6.3	6.0	5.7	5.1	5.2	7.4	6.3	4.6
	13	4	2.6	1.8	2.7	2.5	2.0	3.1	3.0	2.4	2.9	2.5	2.2	2.0
		8	6.6	5.7	6.4	6.3	5.4	5.4	5.3	4.7	5.3	5.4	5.3	4.0
		12	6.8	6.9	7.1	6.7	7.2	6.7	6.5	5.4	5.1	8.9	7.9	6.7

(Sheet 3 of 5)

Table 5 (Continued)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft (Continued)														
101	15	4	3.1	2.3	3.1	2.7	2.6	3.1	2.3	2.3	3.0	2.6	2.2	2.0
		8	6.7	6.1	6.2	6.0	5.2	4.9	5.1	4.9	5.7	4.9	5.6	4.1
		14	7.7	7.4	7.3	7.1	8.0	7.2	7.4	6.8	6.7	9.4	7.8	8.1
	17	6	5.3	4.4	5.3	4.0	3.9	3.9	3.7	3.8	4.8	3.3	3.9	2.9
88	5	6	1.2	1.6	1.0	1.4	1.7	1.8	2.3	2.1	2.4	3.2	2.0	2.2
	7	6	1.7	2.3	2.0	2.1	1.7	2.0	2.5	2.5	2.6	3.4	2.8	2.5
		10	4.0	3.8	2.9	2.9	4.0	4.0	3.4	4.2	6.5	4.5	4.3	5.1
	9	4	1.8	2.0	1.6	2.3	1.5	1.7	1.8	2.2	2.6	2.3	2.0	2.0
		8	3.1	3.4	2.8	3.4	3.2	3.1	3.3	3.6	3.7	3.9	4.2	3.2
		12	5.6	5.2	5.2	5.1	5.7	5.6	5.2	5.8	8.1	6.4	7.3	4.6
	11	6	3.0	3.2	2.7	3.4	3.0	3.1	4.6	4.2	3.9	3.5	3.2	3.2
		10	5.4	5.1	4.5	5.4	5.6	5.1	5.4	5.1	6.2	5.9	5.4	6.0
		14	7.0	6.8	5.7	6.6	7.3	6.6	7.3	6.7	9.7	7.7	8.3	7.2
		18	7.0	6.8	6.9	6.8	7.6	7.8	7.7	7.3	9.4	8.5	7.5	9.5
	13	6	3.2	4.1	3.3	5.5	3.4	3.6	5.5	4.6	3.9	3.4	3.6	4.4
		10	6.1	5.6	5.2	6.0	6.1	6.0	6.2	5.2	6.7	5.2	5.5	6.9
		14	7.7	6.9	6.5	6.2	7.8	7.2	6.4	6.7	9.0	7.9	9.0	8.9

(Sheet 4 of 5)

Table 5 (Concluded)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft (Continued)														
88	13	18	7.9	7.1	6.6	6.8	7.9	7.6	7.0	6.9	9.3	9.0	7.8	9.5
	15	16	8.9	6.6	6.6	7.1	7.1	6.7	7.2	6.6	9.4	8.0	8.9	8.9
75	5	6	2.0	3.3	1.6	1.9	2.2	2.3	2.1	2.4	2.8	2.3	2.8	2.5
	7	6	2.1	4.3	2.6	2.2	2.7	2.5	2.6	2.9	2.7	2.7	4.1	3.7
		10	4.3	4.2	3.8	3.9	5.0	4.5	4.5	4.5	5.5	6.0	5.3	4.4
	9	4	2.5	3.6	2.3	2.0	2.3	1.9	1.9	1.9	2.0	2.1	3.0	2.4
		8	3.9	4.7	3.0	3.9	3.8	3.6	3.3	3.1	4.4	3.5	4.3	5.4
	11	6	3.9	4.3	3.1	3.2	3.4	2.6	2.8	2.3	3.3	3.0	3.8	3.5
		10	6.8	6.4	5.2	5.0	6.2	4.9	4.9	5.4	6.0	4.5	6.5	6.4
		14	6.9	6.1	6.5	6.3	7.2	6.2	6.5	6.5	7.4	6.1	6.6	7.7
56	5	4	1.9	1.6	1.8	1.3	1.7	1.8	1.7	1.2	1.0	1.7	2.0	1.6
	7	4	1.5	1.9	2.6	1.3	1.8	1.7	2.6	1.5	1.9	1.6	3.1	2.4
swl = +12.0 ft														
88	15	18	7.3	8.1	8.0	7.4	7.7	7.5	8.6	8.0	11.9	9.5	7.3	10.4
swl = +13.6 ft														
88	13	20	9.2	9.7	9.0	10.3	10.5	9.9	9.9	9.9	12.3	10.6	9.2	11.2

(Sheet 5 of 5)

Table 6
Wave Heights for Plan 6

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft														
101	5	6	0.7	0.6	0.9	0.6	0.7	0.7	1.9	1.6	2.1	2.0	2.2	2.1
	7	8	1.8	2.1	1.5	2.5	1.6	1.8	3.2	3.8	4.5	4.7	4.2	3.4
	9	4	1.5	1.6	1.1	1.4	1.2	1.5	2.6	2.6	2.9	2.6	2.5	2.4
		8	2.5	2.5	1.8	2.7	2.0	2.0	4.1	4.6	4.3	5.0	4.5	3.1
		12	3.7	3.9	3.1	4.4	3.0	2.6	5.1	5.6	5.3	7.4	6.7	5.5
	11	6	2.6	2.2	1.8	2.1	1.6	1.6	3.5	3.1	3.4	3.0	5.0	2.9
		10	3.8	3.9	3.1	4.5	3.7	3.1	6.3	5.4	5.0	8.0	6.5	5.3
	13	4	1.9	1.3	1.3	1.5	1.2	1.4	3.0	2.4	2.8	2.3	2.2	2.2
		8	3.8	3.3	2.7	3.6	2.6	2.6	6.3	5.4	5.3	5.2	5.1	4.0
		12	4.3	4.5	3.8	4.7	4.2	3.2	7.1	5.8	5.7	8.3	7.1	6.7
	15	4	1.7	1.9	1.4	1.9	1.7	1.5	2.6	2.6	2.9	2.5	2.3	2.0
		8	3.2	3.6	2.5	3.7	2.7	2.4	5.7	4.9	5.1	5.9	5.4	4.0
		14	4.1	4.7	3.7	4.8	4.1	3.4	7.1	7.5	7.9	8.9	8.0	7.9
	17	6	2.6	2.5	2.3	2.5	1.9	2.0	4.3	3.5	4.1	3.5	4.2	3.3

Table 7
Wave Heights for Plan 7

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft														
101	5	6	0.6	0.6	0.6	0.5	0.4	0.4	2.1	2.1	3.3	2.6	2.7	2.5
	7	8	1.0	1.0	0.8	1.4	1.0	1.0	4.6	4.4	4.9	5.0	3.7	3.4
	9	4	0.9	0.8	0.8	0.7	0.7	0.6	3.6	3.0	3.0	2.9	2.5	2.3
		8	1.5	1.3	1.2	1.5	1.3	1.2	5.6	5.1	4.9	5.3	5.1	3.4
		12	2.0	1.8	1.5	1.9	1.5	1.4	7.6	6.5	5.8	7.5	7.5	4.9
	11	6	2.2	1.3	1.2	1.2	1.1	1.1	5.1	3.6	3.6	3.6	4.6	2.8
		10	2.9	1.9	1.8	2.2	1.8	1.6	7.3	5.9	5.8	7.0	6.8	4.3
	13	4	1.8	1.0	0.8	0.9	1.2	1.0	4.0	2.7	2.8	2.5	2.4	2.2
		8	2.8	1.9	1.8	1.8	1.8	1.6	7.2	5.7	5.8	5.4	6.1	4.2
		12	2.8	2.5	2.1	2.5	2.2	2.0	8.8	6.7	6.4	8.3	8.0	6.5
	15	4	1.7	0.9	0.9	1.2	1.0	1.0	3.0	2.5	3.0	2.4	1.9	2.5
		8	2.8	2.1	1.6	1.9	1.6	1.4	7.0	5.2	5.8	5.4	6.2	3.9
		14	3.9	2.5	2.0	2.6	2.1	1.8	9.1	7.3	7.2	9.1	6.9	6.5
	17	6	2.0	1.5	1.4	1.4	1.2	1.2	4.9	4.0	4.1	3.3	3.7	3.5
swl = +8.8 ft														
88	5	6	0.2	0.2	0.1	0.3	0.2	0.2	1.8	2.4	2.7	3.5	2.5	2.2
	7	6	0.6	0.5	0.3	0.5	0.4	0.4	2.3	2.6	3.2	3.2	2.6	2.2
		10	1.0	1.1	0.7	0.8	0.8	0.9	3.4	4.0	6.3	5.0	5.2	3.7

(Continued)

Table 7 (Concluded)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft (Continued)														
88	9	4	0.8	0.6	0.4	0.5	0.4	0.5	2.7	2.5	2.7	2.4	1.9	2.1
		8	1.0	1.1	0.8	0.8	0.8	0.8	3.6	3.6	4.2	4.1	4.2	3.9
		12	1.9	1.6	1.3	1.4	1.6	1.2	6.0	5.4	7.7	6.9	7.3	4.2
	11	6	1.4	1.0	1.1	0.9	1.1	1.0	4.8	4.4	4.3	3.8	3.8	3.8
		10	2.2	1.8	1.4	1.6	1.5	1.3	6.2	5.0	6.4	5.6	6.1	6.0
		14	2.9	2.6	1.9	1.8	1.9	1.7	8.2	6.4	8.9	7.9	9.0	7.3
		18	3.5	2.7	2.0	2.0	2.4	1.9	9.1	7.1	8.8	8.9	8.6	8.8
	13	6	1.4	1.2	1.0	1.2	1.1	1.0	5.3	5.0	4.3	3.6	3.2	4.0
		10	2.5	1.7	1.5	1.7	1.6	1.6	7.2	5.6	6.1	5.7	5.5	6.5
		14	4.0	2.7	2.0	1.9	2.1	1.8	7.6	6.0	8.9	8.2	8.2	8.6
		18	4.2	2.9	2.3	2.0	2.5	2.2	8.5	6.6	9.1	8.4	8.1	9.6
	15	16	4.7	3.0	2.3	2.2	2.4	2.0	7.4	6.4	9.2	8.8	9.2	8.2
swl = +12.0 ft														
88	15	18	5.9	4.4	3.7	4.3	3.9	3.5	10.3	8.5	11.6	11.1	7.8	11.0
swl = +13.6 ft														
88	13	20	6.2	5.9	5.2	6.3	5.9	5.5	10.8	10.0	12.3	10.5	9.9	12.0

Table 8
Wave Heights for Plan 8

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft														
101	5	6	2.4	2.9	2.3	1.0	0.8	1.0	2.2	2.2	3.2	2.8	2.5	2.6
	7	8	3.8	4.2	3.1	2.2	1.3	1.8	4.7	4.4	5.1	5.4	4.4	3.3
	9	4	2.7	2.7	2.2	1.5	0.9	1.5	4.3	3.5	3.0	3.2	2.4	2.1
		8	5.2	6.1	3.8	2.9	1.9	2.4	6.8	5.9	4.8	6.2	5.6	3.2
		12	6.2	6.3	5.1	4.3	2.7	2.9	6.7	6.1	5.7	8.4	6.6	6.0
	11	6	4.2	4.3	3.0	2.6	1.7	2.1	4.8	3.8	3.7	3.5	3.9	3.0
		10	6.9	6.8	5.0	4.7	3.2	3.2	7.9	5.7	5.2	8.4	6.2	6.0
	13	4	2.9	2.6	2.1	1.7	1.4	1.8	4.0	2.7	3.1	2.9	2.1	2.5
		8	6.7	6.4	5.0	3.6	3.0	3.0	8.0	5.7	6.2	5.4	5.8	4.5
		12	7.5	7.1	6.0	5.5	3.1	3.4	8.6	6.7	5.9	9.6	7.5	7.6
	15	4	2.6	2.4	2.2	1.7	1.7	1.8	3.3	2.6	3.3	2.6	2.2	2.0
		8	5.4	6.5	5.1	4.1	3.3	3.0	7.2	5.2	6.1	5.0	5.6	4.7
		14	7.5	7.1	6.5	4.6	3.4	3.3	8.6	7.9	7.7	9.3	6.5	7.0
	17	6	3.9	5.0	3.6	2.6	2.0	2.2	4.7	4.4	4.7	3.4	3.8	3.4
88	5	6	2.0	2.7	1.4	1.2	0.9	1.1	2.3	3.2	3.0	3.8	2.9	3.4
	7	6	1.9	2.6	1.9	1.2	0.9	1.5	2.7	3.6	3.9	3.7	3.2	3.8

(Continued)

Table 8 (Concluded)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft (Continued)														
88	7	10	3.7	4.0	2.9	1.9	2.0	2.0	4.1	5.4	6.8	5.6	5.2	4.7
	9	4	1.8	2.0	1.5	1.2	0.9	1.4	2.3	2.7	2.8	2.4	2.0	2.6
		8	4.0	4.3	2.5	1.7	1.6	1.9	4.3	4.5	4.8	4.6	3.8	5.3
		12	6.0	5.4	4.2	3.0	2.7	3.0	6.8	6.2	8.3	6.3	6.8	6.5
	11	6	3.0	2.9	2.0	1.7	1.4	1.8	5.0	4.7	4.0	4.1	2.9	3.9
		10	5.8	5.4	3.7	3.2	2.6	2.6	7.2	5.6	6.4	6.4	5.5	6.8
		14	7.1	6.3	4.7	3.9	3.1	3.1	9.0	7.0	9.1	8.2	7.8	8.8
		18	6.8	6.3	5.3	4.4	3.9	3.2	9.1	7.8	9.0	8.6	8.2	9.4
	13	6	3.2	3.7	2.2	1.8	1.6	1.8	5.9	4.8	4.3	3.7	3.5	4.1
		10	5.3	5.4	3.8	3.2	3.0	2.7	8.0	5.5	6.4	6.0	5.2	7.2
		14	7.4	6.5	5.8	4.3	3.5	3.2	8.3	6.4	8.6	9.2	8.9	8.9
		18	6.6	5.9	4.9	4.6	3.7	3.2	9.2	6.9	9.3	9.3	7.1	10.1
	15	16	7.2	6.7	5.4	4.7	3.8	3.2	8.4	6.5	10.3	9.2	9.0	9.9
swl = +12.0 ft														
88	15	18	9.3	7.8	6.6	6.8	5.3	4.8	9.9	8.8	12.1	11.2	8.6	11.9
swl = +13.6 ft														
88	13	20	9.4	9.5	8.2	8.6	6.3	5.9	11.6	10.3	12.4	10.7	10.2	13.2

Table 9
Wave Heights for Plan 9

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = 0.0 ft														
101	5	6	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.6	2.2	1.3	0.8	0.1
	7	8	0.5	0.1	0.1	0.3	1.7	0.9	1.3	2.3	4.3	2.6	2.1	0.6
	9	4	0.3	0.1	0.1	0.2	1.2	0.7	1.1	2.1	2.6	1.8	1.7	0.5
		8	1.6	1.1	1.9	1.5	2.9	1.6	2.2	3.1	4.5	2.9	3.6	1.5
		12	2.2	1.5	2.0	2.3	3.7	1.9	2.6	3.3	5.5	4.2	4.4	2.3
	11	6	0.7	0.1	1.0	0.5	2.1	1.3	2.4	2.5	3.7	3.0	2.7	1.3
		10	1.7	0.9	1.6	1.3	2.7	1.7	2.8	3.0	4.8	3.5	4.8	1.9
	13	4	0.4	0.1	0.3	<0.1	0.9	0.8	1.3	1.7	1.8	1.7	1.6	0.5
		8	1.1	0.2	0.9	0.5	2.2	1.4	1.7	2.5	4.3	3.0	3.2	1.8
		12	2.0	1.1	1.5	1.5	2.9	1.8	3.1	3.2	5.2	3.4	4.9	2.5
	15	4	0.4	0.1	0.4	0.1	0.9	0.7	1.3	1.9	2.0	1.4	1.5	0.7
		8	1.5	1.2	1.1	1.0	2.1	1.4	2.5	2.8	4.4	2.8	3.2	1.9
		14	2.6	1.5	1.9	1.8	3.2	1.8	3.0	3.4	5.0	4.2	4.9	2.9
	17	16	1.0	0.5	0.8	0.7	1.5	1.3	2.1	2.4	3.2	2.0	2.4	1.6

(Sheet 1 of 3)

Table 9 (Continued)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft														
101	5	6	2.3	2.5	2.5	2.5	2.5	3.0	3.9	3.1	3.2	2.6	2.6	2.4
	7	8	3.7	4.7	3.5	4.8	3.8	4.3	5.0	4.4	4.4	4.5	4.2	3.2
	9	4	2.5	2.6	1.9	4.8	2.6	2.6	3.6	2.7	2.6	3.1	1.9	1.8
		8	4.7	6.1	4.1	5.2	4.6	4.5	4.9	5.4	4.5	4.8	5.3	3.2
		12	6.0	6.6	6.3	7.3	6.1	6.1	6.7	6.0	5.8	8.3	7.4	4.7
	11	6	3.7	4.4	3.7	4.6	4.6	4.7	4.1	3.9	3.9	3.5	3.3	2.9
		10	6.9	6.5	6.8	7.5	6.5	5.9	6.4	5.8	5.1	7.6	6.3	4.8
	13	4	3.2	2.7	2.3	3.1	3.1	3.3	4.8	4.2	3.8	2.0	2.2	2.3
		8	5.9	6.7	5.7	6.5	5.5	4.9	5.6	6.2	5.3	5.2	5.7	4.7
		12	7.9	7.7	7.6	7.6	6.7	6.0	6.7	5.9	5.8	9.1	8.0	6.9
	15	4	2.7	3.4	2.4	3.5	4.0	3.3	4.8	4.2	4.3	2.5	2.3	1.8
		8	4.6	6.2	6.0	7.0	5.7	5.7	7.7	7.6	8.1	4.9	5.2	4.0
		14	7.2	8.3	7.0	8.1	7.9	7.5	7.5	8.0	8.2	9.1	8.1	8.0
	17	6	4.0	5.8	4.9	6.4	5.5	5.0	6.1	6.9	6.6	3.3	3.7	3.4
88	5	6	2.2	3.0	1.9	3.4	2.8	3.0	3.7	3.3	2.8	3.8	2.6	2.9
	7	6	1.8	2.9	2.7	3.3	3.3	3.3	3.9	4.1	4.0	3.9	3.1	2.7
		10	4.5	4.7	4.1	4.3	5.9	5.3	5.3	5.6	6.8	5.9	5.2	4.9
	9	4	1.9	2.4	1.9	2.5	3.3	2.9	2.7	3.1	2.8	2.4	2.0	2.0
		8	4.6	5.4	3.7	4.4	5.3	4.9	5.4	5.9	4.6	5.0	4.4	4.2
		12	6.4	6.2	5.4	6.1	6.7	6.1	6.7	7.2	8.5	7.2	7.4	5.9
	11	6	3.5	4.5	3.3	4.3	4.3	4.0	5.1	4.3	3.2	3.9	3.4	3.5
		10	6.3	6.2	5.4	6.2	6.5	5.7	6.6	6.8	7.3	7.5	6.0	5.0

(Sheet 2 of 3)

Table 9 (Concluded)

Test Wave			Wave Height at Indicated Gage Location (ft)											
Direction deg	Period sec	Height ft	Gage 1	Gage 2	Gage 3	Gage 4	Gage 5	Gage 6	Gage 7	Gage 8	Gage 9	Gage 10	Gage 11	Gage 12
swl = +8.8 ft (Continued)														
88	11	14	7.5	7.2	6.2	5.8	7.3	6.6	7.2	7.8	9.6	7.9	8.1	7.4
		18	7.6	6.9	6.8	6.9	7.7	6.6	7.7	8.2	10.1	9.1	8.8	9.4
	13	6	3.9	4.8	3.3	5.2	4.6	4.6	5.0	5.2	3.9	3.7	3.8	3.6
		10	6.5	5.9	5.3	6.0	6.1	5.7	6.6	6.8	8.4	6.0	5.4	6.8
		14	8.0	7.0	6.5	6.6	7.7	6.9	7.4	7.6	9.5	9.6	9.1	7.8
		18	7.7	6.9	6.4	6.6	8.4	7.4	7.6	8.5	10.2	9.2	8.7	9.5
	15	16	7.2	6.6	6.1	6.5	7.6	6.9	7.4	7.6	10.3	9.7	8.8	9.0
swl = +12.0 ft														
88	15	18	8.4	7.2	7.2	9.1	9.3	9.3	9.0	9.6	11.5	10.9	7.6	10.8
swl = +13.6 ft														
88	13	20	10.2	9.7	9.4	10.8	10.1	10.5	11.0	10.9	13.8	10.6	11.3	12.0
swl = +8.8 ft														
75	5	6	1.4	1.9	1.4	1.0	1.0	1.7	2.0	2.1	2.2	2.5	2.3	2.2
	7	6	2.1	4.0	2.2	1.6	2.2	2.0	2.4	2.5	2.1	2.3	3.6	3.7
		10	4.3	4.0	3.3	3.0	5.1	3.7	4.0	4.0	4.9	5.7	4.9	4.3
	9	4	2.4	2.9	1.8	1.6	2.4	1.8	1.6	1.7	2.1	1.8	2.2	2.2
		8	3.8	4.5	2.8	3.6	4.2	3.3	3.1	2.7	3.4	3.2	4.2	4.6
	11	6	4.2	4.5	2.9	3.1	3.7	2.8	3.0	3.3	3.3	2.9	3.5	4.4
		10	6.8	5.7	5.0	5.3	6.2	5.4	6.4	6.4	6.0	5.5	7.1	5.7
		14	7.5	6.4	5.5	5.8	7.2	6.0	7.1	7.3	8.8	6.8	7.3	7.8
56	5	4	1.3	1.4	1.1	0.7	0.9	0.8	1.1	1.5	0.9	1.2	1.9	1.5
	7	4	1.5	1.7	2.1	1.3	1.7	1.8	2.1	1.4	1.8	1.7	2.3	2.2

(Sheet 3 of 3)

Table 10
Comparison of Wave Heights in Navigation Channel for Existing Conditions and Plan 9

Test Wave			Plan 9					Existing Conditions				
			Wave Height at Indicated Gage Location (ft)									
Direction deg	Period sec	Height ft	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17
swl = +8.8 ft												
101	5	6	1.0	1.2	1.3	4.2	6.7	0.1	0.5	1.9	4.2	7.7
	7	8	2.2	2.3	2.5	5.8	9.8	0.3	1.0	2.0	5.6	9.4
	9	4	1.0	1.4	1.8	4.2	6.7	0.5	0.6	1.1	3.2	7.0
		8	2.7	2.2	2.9	6.1	9.6	0.8	1.0	1.9	4.7	9.8
		12	3.4	3.6	4.0	7.7	10.9	1.2	1.6	2.6	6.7	10.1
	11	6	2.2	2.2	3.1	7.1	8.6	0.8	1.0	2.0	6.2	8.9
		10	3.7	3.4	4.0	7.6	11.6	1.1	1.6	2.9	7.9	10.8
	13	4	1.7	1.9	2.2	5.8	6.0	0.3	0.9	1.7	4.4	6.4
		8	2.7	3.1	4.1	5.5	11.5	0.8	1.6	2.6	6.5	10.9
		12	4.0	4.4	4.4	6.3	10.3	1.1	2.1	3.1	6.2	9.8
	15	4	1.3	1.8	2.4	4.0	5.8	0.4	0.9	1.6	3.9	6.0
		8	2.8	2.9	4.0	6.2	10.5	0.7	1.4	2.6	6.4	10.4
		14	4.5	4.9	5.3	6.4	8.8	0.9	2.0	3.3	6.1	8.1
	17	6	2.6	3.2	3.3	5.4	9.8	0.5	1.2	2.1	6.1	9.9
swl = 0.0 ft												
101	5	6	0.1	0.1	0.2	2.3	5.7	0.1	0.1	0.1	1.3	5.9
	7	8	0.5	0.6	0.6	3.7	6.3	1.1	0.8	0.5	2.6	6.5
	9	4	0.7	0.7	0.5	2.8	5.4	0.7	0.5	0.4	2.6	6.4
		8	1.2	1.0	1.0	3.4	6.7	1.2	1.0	1.0	3.3	7.4
		12	1.7	1.0	1.3	3.9	6.6	1.1	1.2	1.0	4.1	7.6

(Sheet 1 of 3)

Table 10 (Concluded)

Test Wave			Plan 9					Existing Conditions				
			Wave Height at Indicated Gage Location (ft)									
Direction deg	Period sec	Height ft	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17
swl = +8.8 ft (Continued)												
88	13	14	5.5	5.0	5.5	9.1	10.7	1.1	2.1	4.1	8.7	10.4
		18	5.1	5.0	5.8	9.0	12.0	1.2	2.3	3.9	8.6	11.2
	15	16	5.7	5.4	6.0	8.2	11.4	1.1	2.1	3.6	8.5	11.0
swl = +12.0 ft												
88	15	18	6.6	6.0	7.0	10.1	12.5	2.3	3.9	6.1	9.6	13.0
swl = +13.6 ft												
88	13	20	7.9	6.1	7.4	10.5	13.8	3.5	5.1	7.4	11.7	14.2
swl +8.8 ft												
75	5	6	1.0	1.5	1.1	3.0	3.3	0.2	0.4	0.9	2.2	2.7
	7	6	1.2	1.9	1.4	2.9	4.1	0.2	0.8	1.1	2.2	4.0
		10	3.2	3.0	3.3	5.0	4.2	0.5	1.2	1.8	4.8	4.8
	9	4	0.9	1.5	1.1	2.0	2.7	0.2	0.7	0.9	2.1	2.6
		8	1.8	2.8	2.6	3.8	4.4	0.5	1.1	1.4	3.5	4.1
	11	6	1.8	2.5	2.2	3.3	4.3	0.5	1.1	1.4	2.8	3.7
		10	3.7	4.2	5.0	5.9	5.8	1.0	1.6	2.1	5.6	5.5
		14	4.7	5.6	5.1	5.4	8.0	1.2	1.9	2.4	4.4	8.2
56	5	4	0.7	1.3	0.9	0.9	1.3	0.1	0.3	0.7	0.7	1.4
	7	4	0.9	1.8	0.8	1.2	1.0	0.2	0.7	0.7	1.0	1.4

(Sheet 3 of 3)

Table 10 (Continued)

Test Wave			Plan 9					Existing Conditions				
			Wave Height at Indicated Gage Location (ft)									
Direction deg	Period sec	Height ft	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17	Gage 13	Gage 14	Gage 15	Gage 16	Gage 17
swl = 0.0 ft (Continued)												
101	11	6	1.0	1.1	1.0	3.4	6.1	0.9	0.6	0.6	2.8	6.1
		10	1.4	1.5	1.3	3.6	5.8	1.1	0.8	0.9	3.4	6.5
	13	4	0.5	0.5	0.8	2.6	5.6	0.5	0.4	0.3	2.5	6.4
		8	1.2	1.2	1.1	3.5	6.4	0.9	0.7	0.7	3.3	6.5
		12	1.2	1.4	1.4	3.8	5.9	1.4	0.8	0.8	3.8	6.7
	15	4	0.4	0.4	0.8	3.0	5.5	0.4	0.3	0.3	2.9	6.5
		8	1.1	1.0	1.1	3.2	6.7	0.6	0.5	0.5	3.1	6.1
		14	1.5	1.3	1.4	3.8	6.2	0.8	0.7	0.7	4.2	6.7
	17	6	0.8	0.9	1.0	3.4	7.2	0.4	0.5	0.3	3.8	7.3
swl = +8.8 ft												
88	5	6	1.0	1.1	1.6	3.1	6.5	0.2	0.2	1.6	3.2	6.0
	7	6	1.1	1.6	2.1	3.9	5.9	0.2	0.3	1.9	3.7	6.4
		10	3.3	3.4	4.3	6.5	9.5	0.4	0.7	2.7	6.4	8.9
	9	4	1.0	1.6	2.2	3.3	4.5	0.3	0.6	1.5	3.4	4.6
		8	2.6	2.5	3.3	5.8	8.8	0.7	1.0	2.5	6.4	9.1
		12	3.6	4.4	5.3	8.1	9.7	0.9	1.6	3.3	6.9	9.8
	11	6	2.3	3.0	3.3	6.7	8.4	0.8	1.1	2.5	6.2	7.5
		10	3.8	4.3	4.7	8.6	9.9	1.3	1.7	3.4	7.4	9.7
		14	5.2	5.3	5.9	8.1	10.0	1.3	2.1	3.9	8.3	9.6
		18	5.8	5.9	6.1	9.2	11.8	1.3	2.4	4.3	8.7	11.0
	13	6	2.1	2.8	3.8	7.7	10.3	0.7	1.2	2.6	7.0	9.6
		10	3.9	4.2	4.7	8.5	11.3	1.0	1.9	3.6	7.4	10.5

(Sheet 2 of 3)

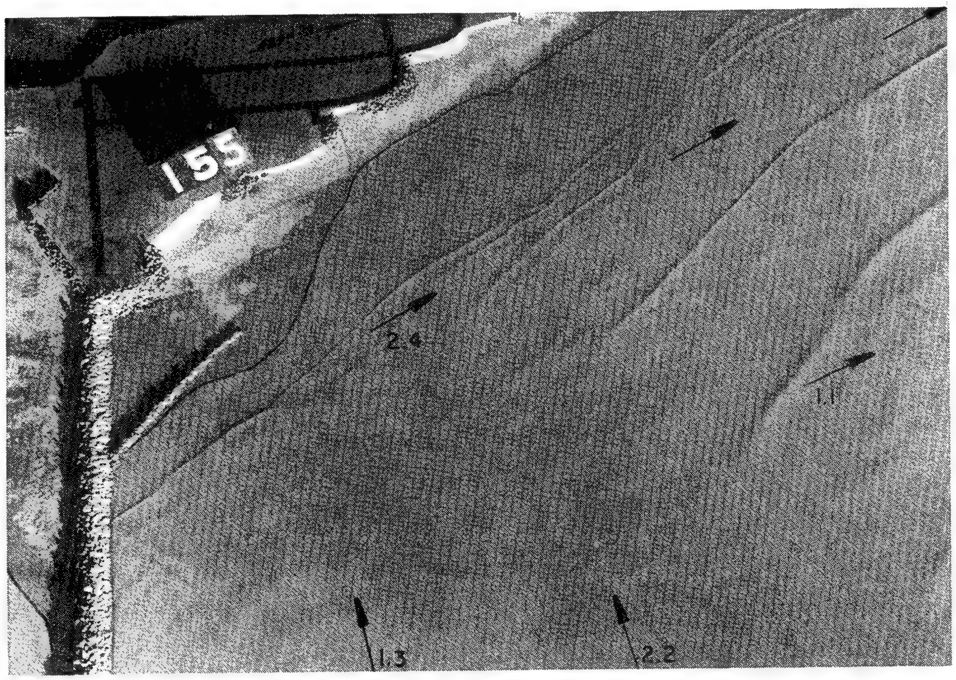


Photo 1. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 13-sec, 12-ft test waves from 101 deg; swl = 0.0 ft

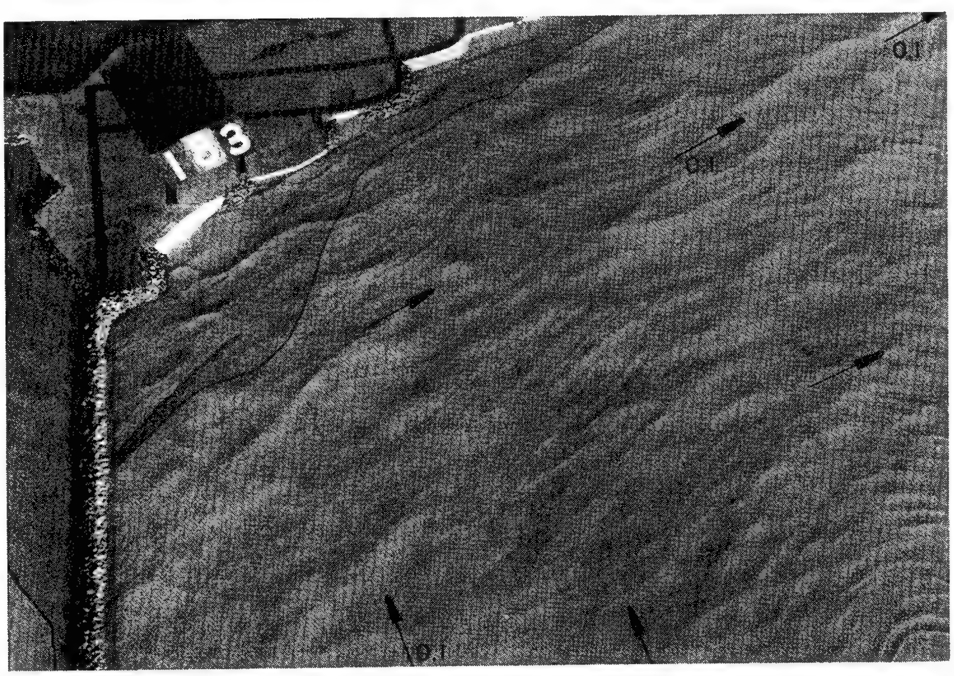


Photo 2. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 6-ft test waves from 101 deg; swl = +8.8 ft

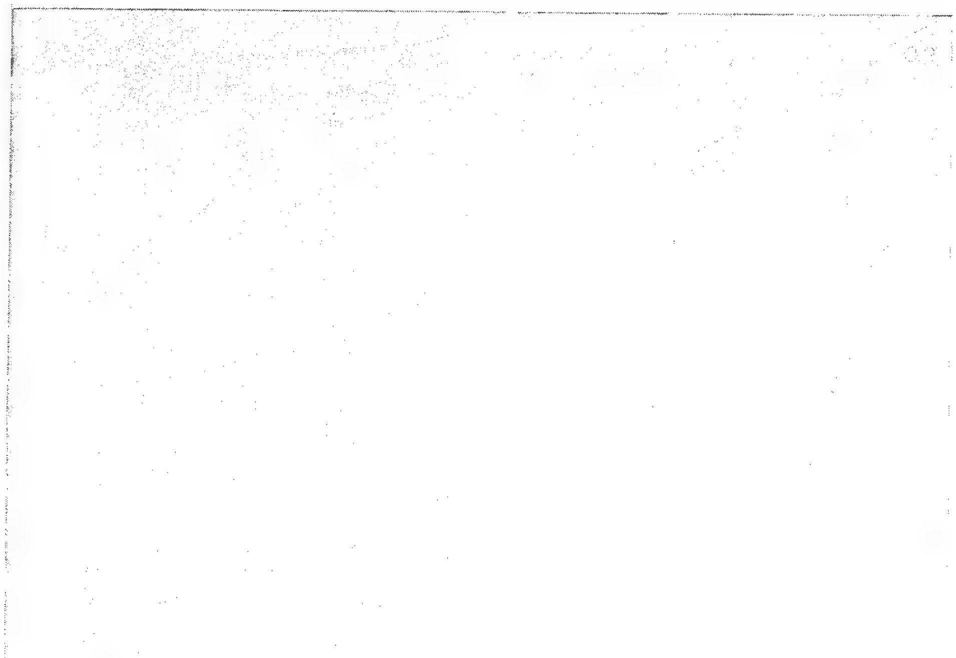


Photo 3. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

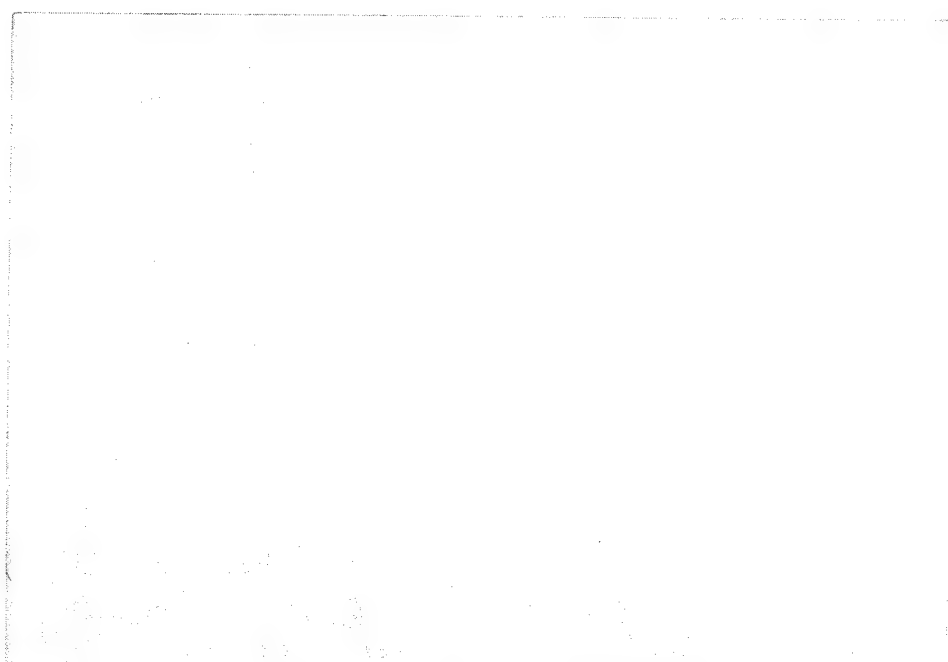


Photo 4. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 15-sec, 14-ft test waves from 101 deg; swl = +8.8 ft

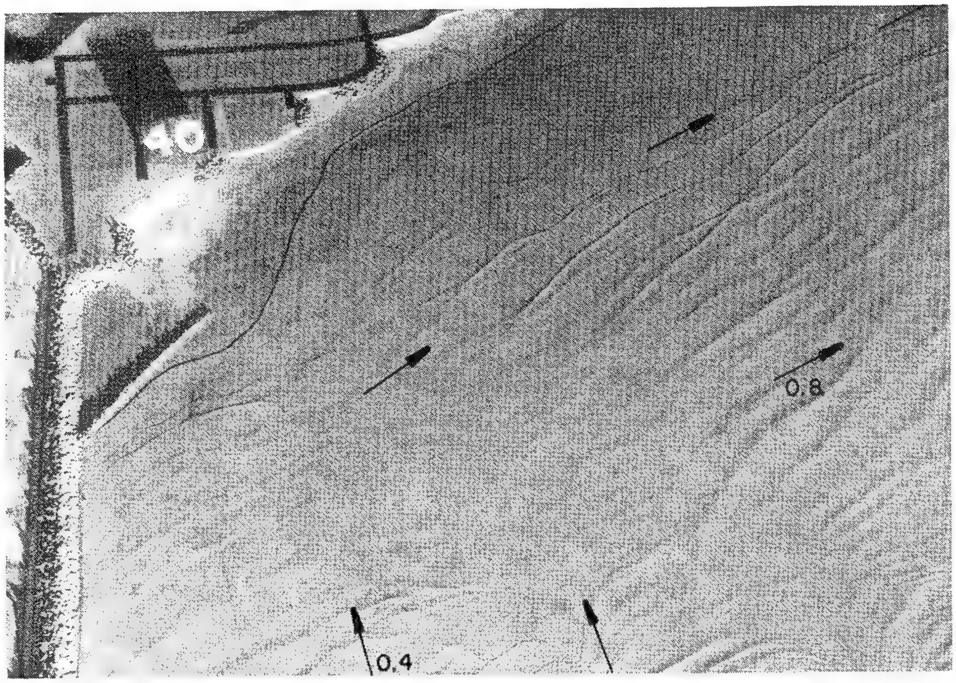


Photo 5. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 6-ft test waves from 88 deg; swl = 0.0 ft

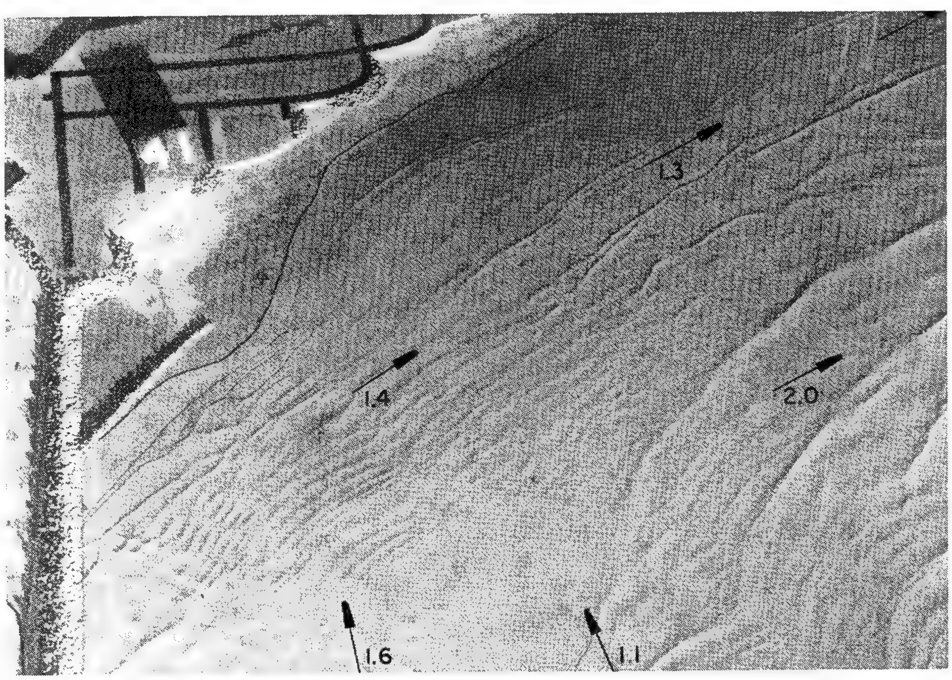


Photo 6. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 14-ft test waves from 88 deg; swl = 0.0 ft

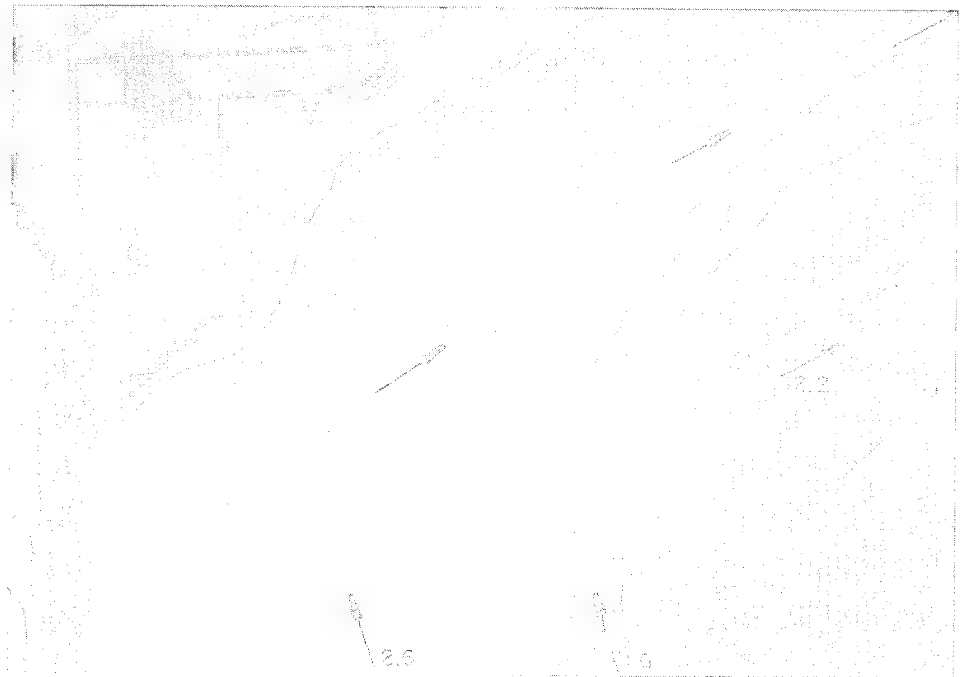


Photo 7. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 13-sec, 18-ft test waves from 88 deg; swl = 0.0 ft

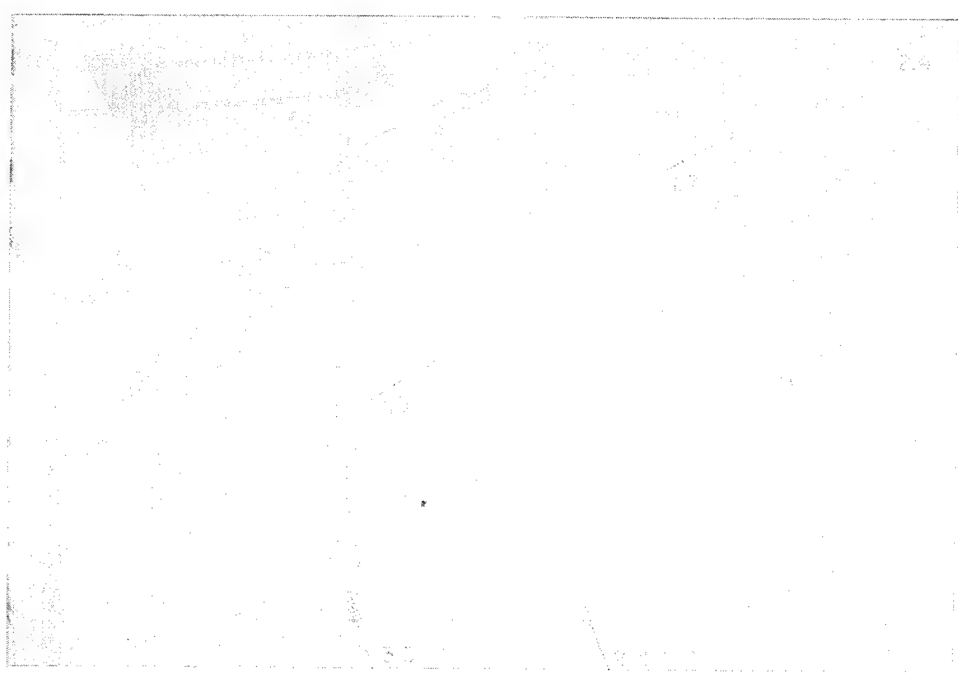


Photo 8. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 15-sec, 16-ft test waves from 88 deg; swl = 0.0 ft

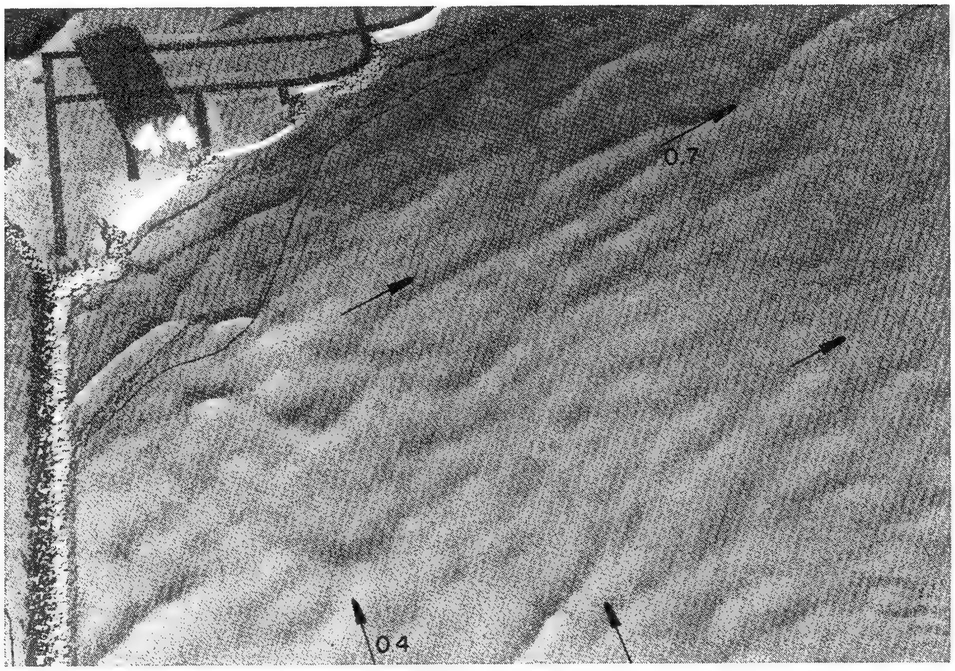


Photo 9. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 6-ft test waves from 88 deg; swl = +8.8 ft

Photo 10. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 14-ft test waves from 88 deg; swl = +8.8 ft

Photo 11. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft

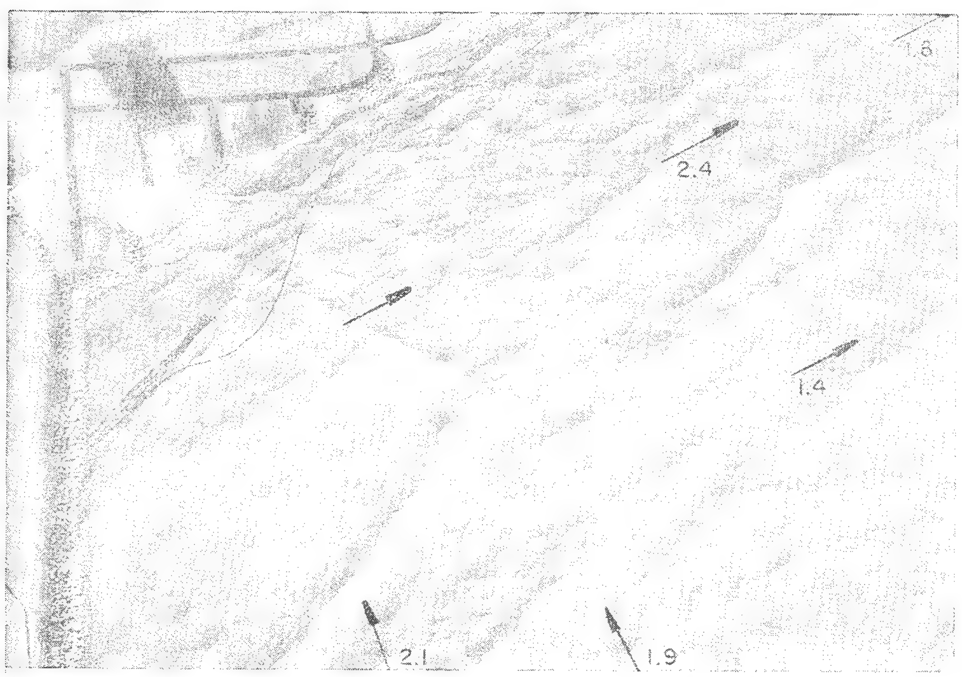


Photo 12. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 15-sec, 16-ft test waves from 88 deg; swl = +8.8 ft

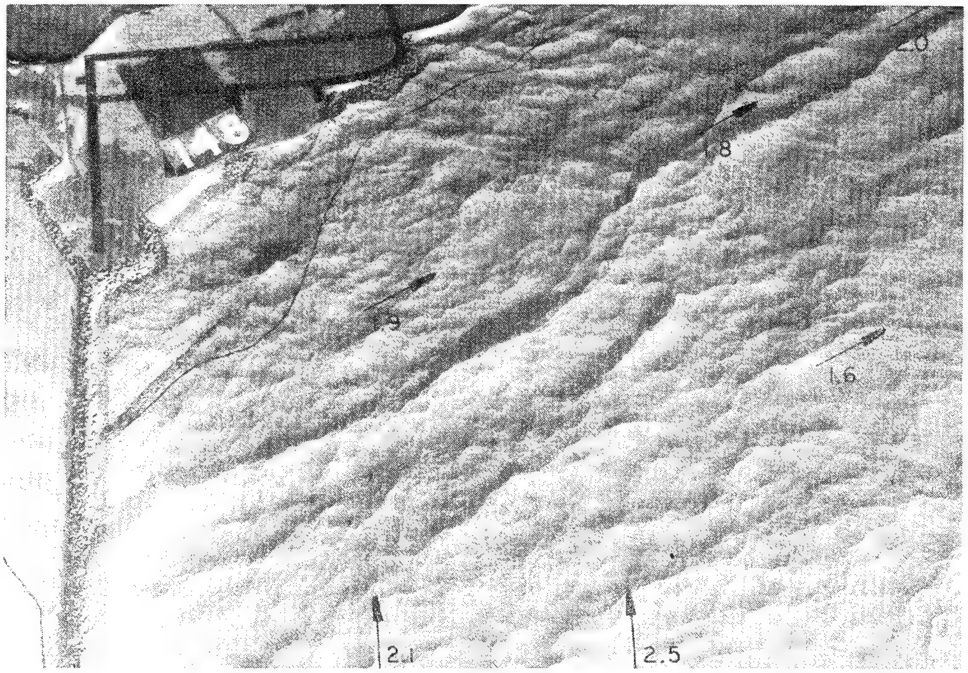


Photo 13. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

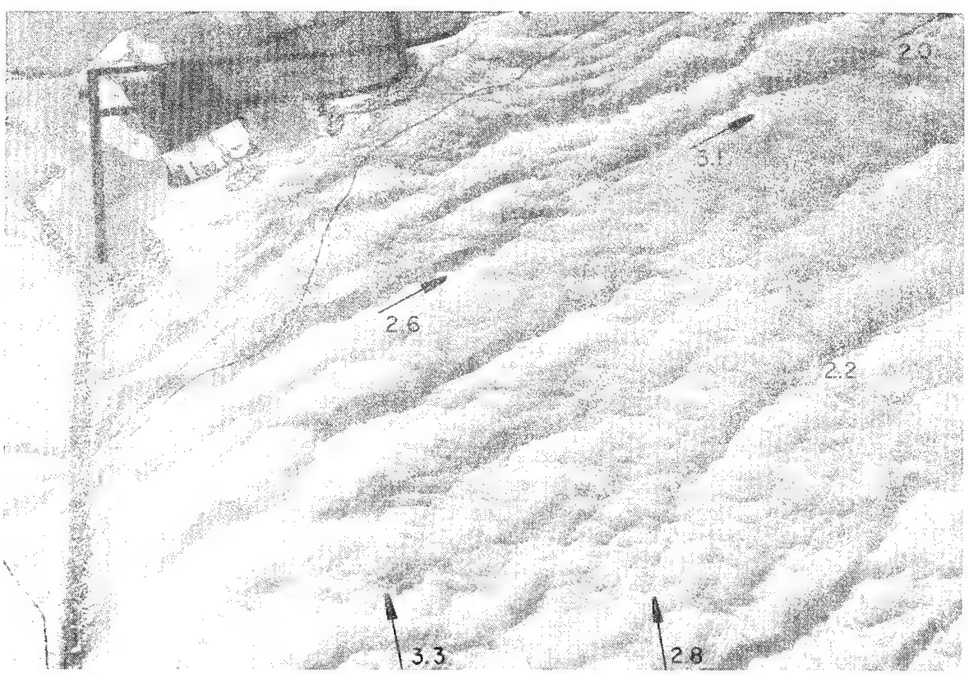


Photo 14. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

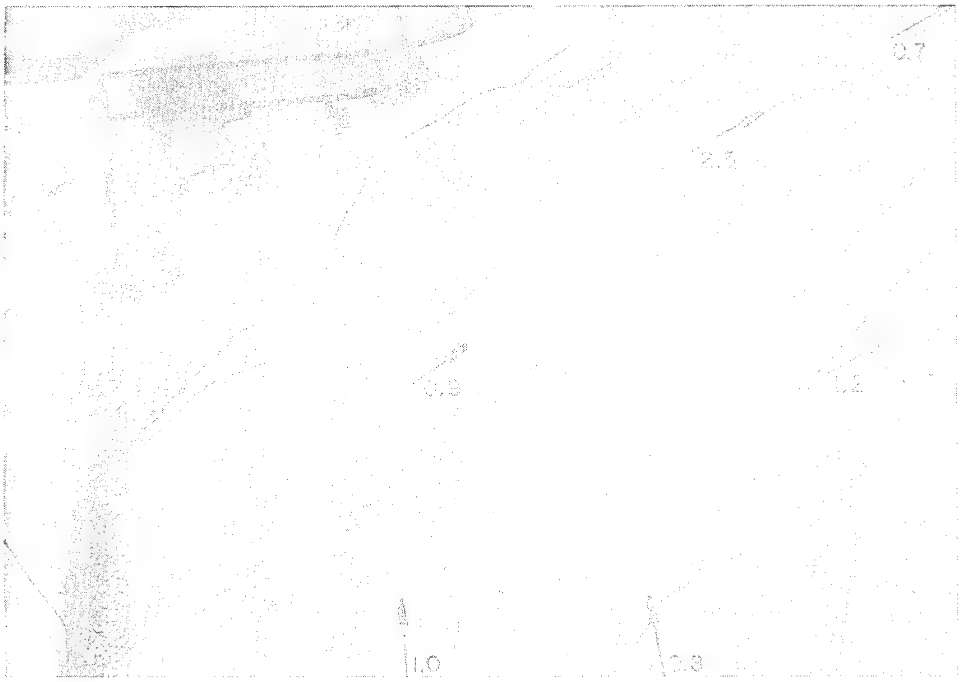


Photo 15. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 14-ft test waves from 75 deg; swl = 0.0 ft

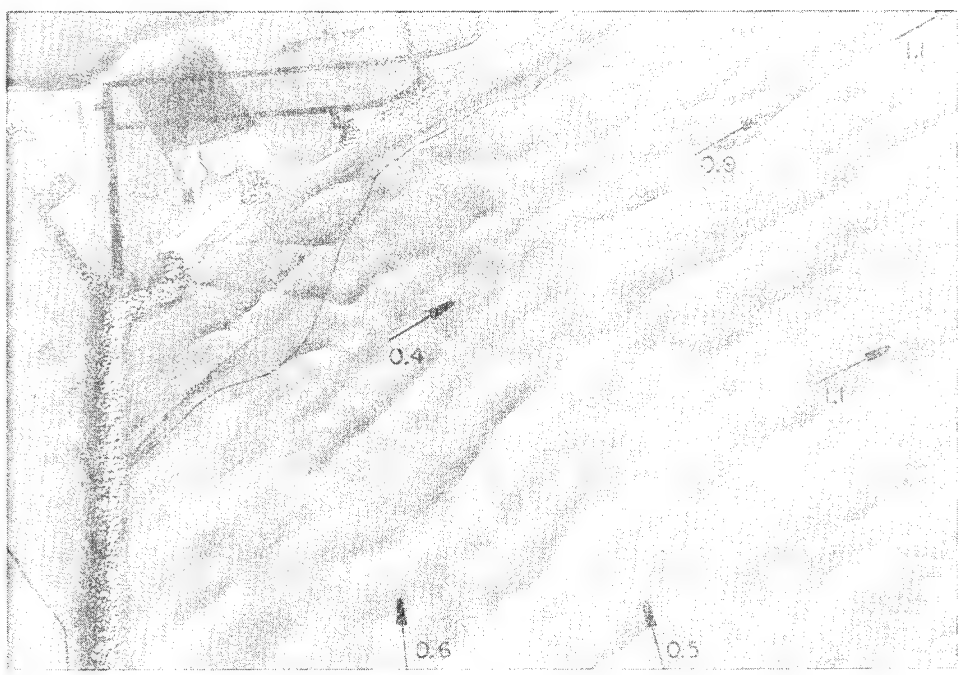


Photo 16. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 9-sec, 8-ft test waves from 75 deg; swl = +8.8 ft

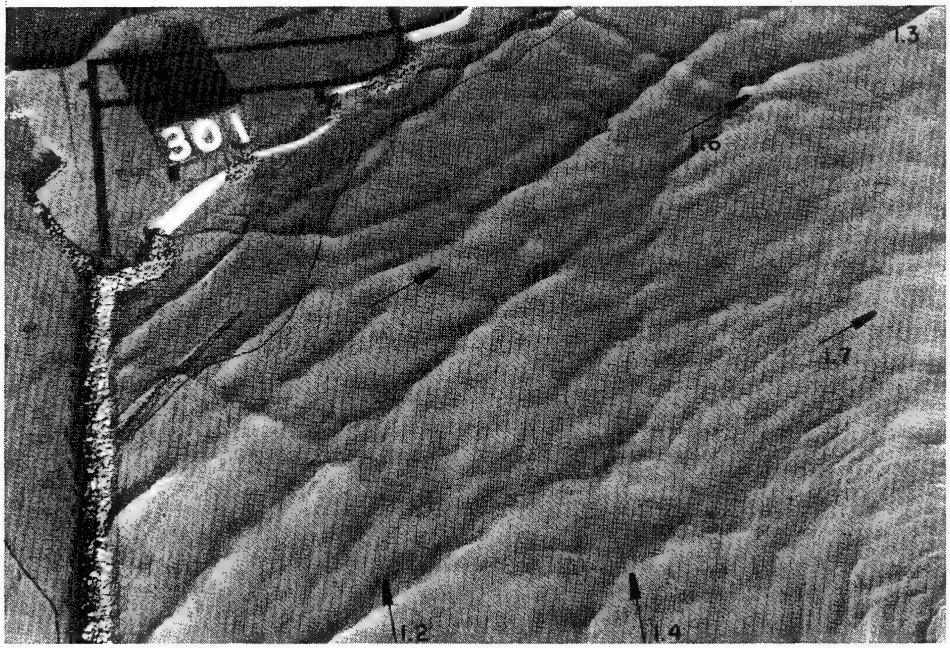


Photo 17. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft

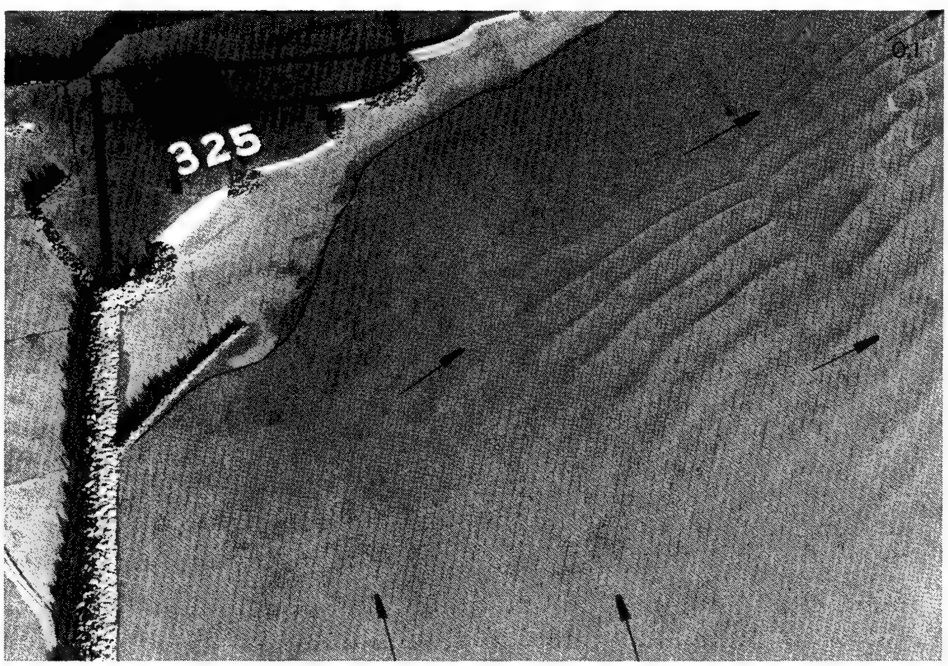
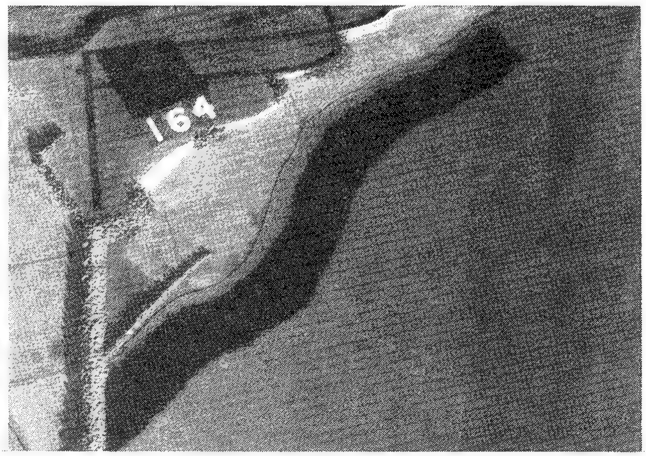
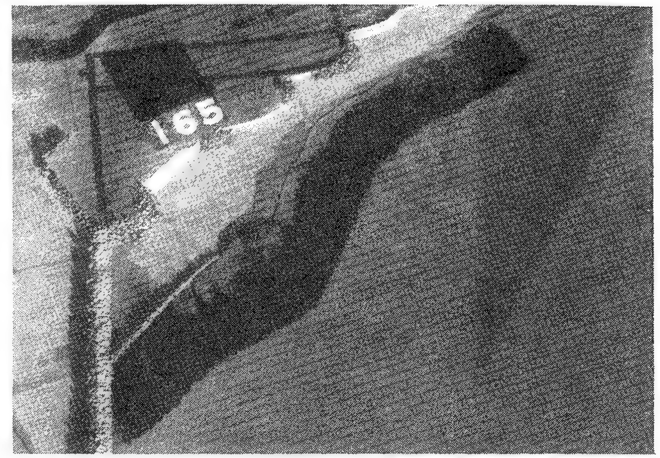


Photo 18. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 4-ft test waves from 56 deg; swl = 0.0 ft

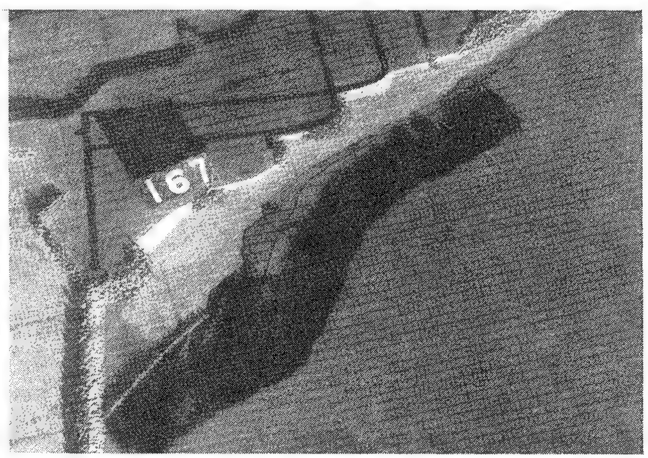
Photo 19. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for existing conditions; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft



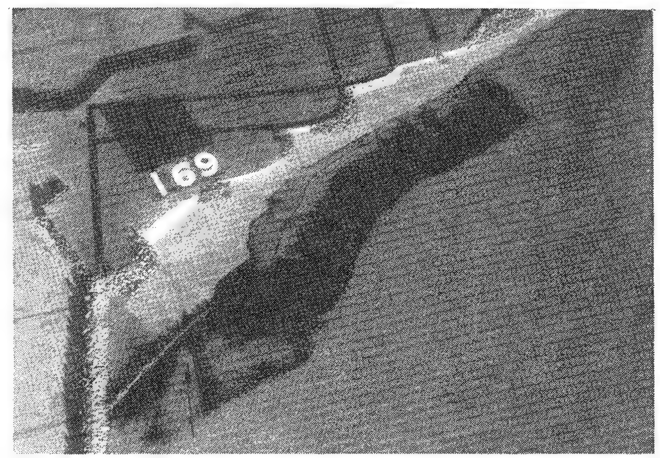
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 20. Progression of sediment tracer movement for existing conditions; 13-sec, 12-ft test waves from 101 deg; swl = 0.0 ft

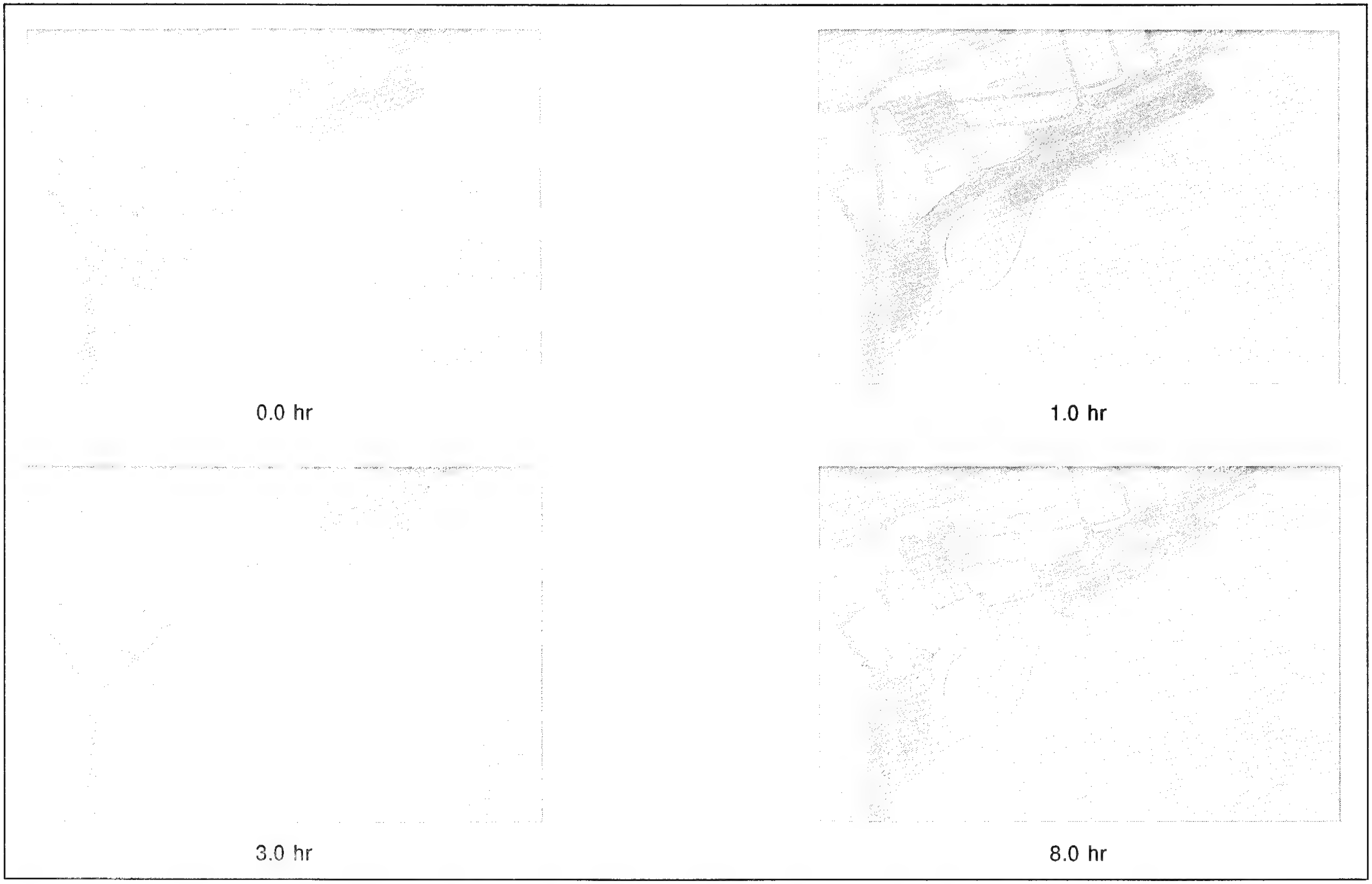


Photo 21. Progression of sediment tracer movement for existing conditions; 11-sec, 6-ft test waves from 101 deg; swl = +8.8 ft

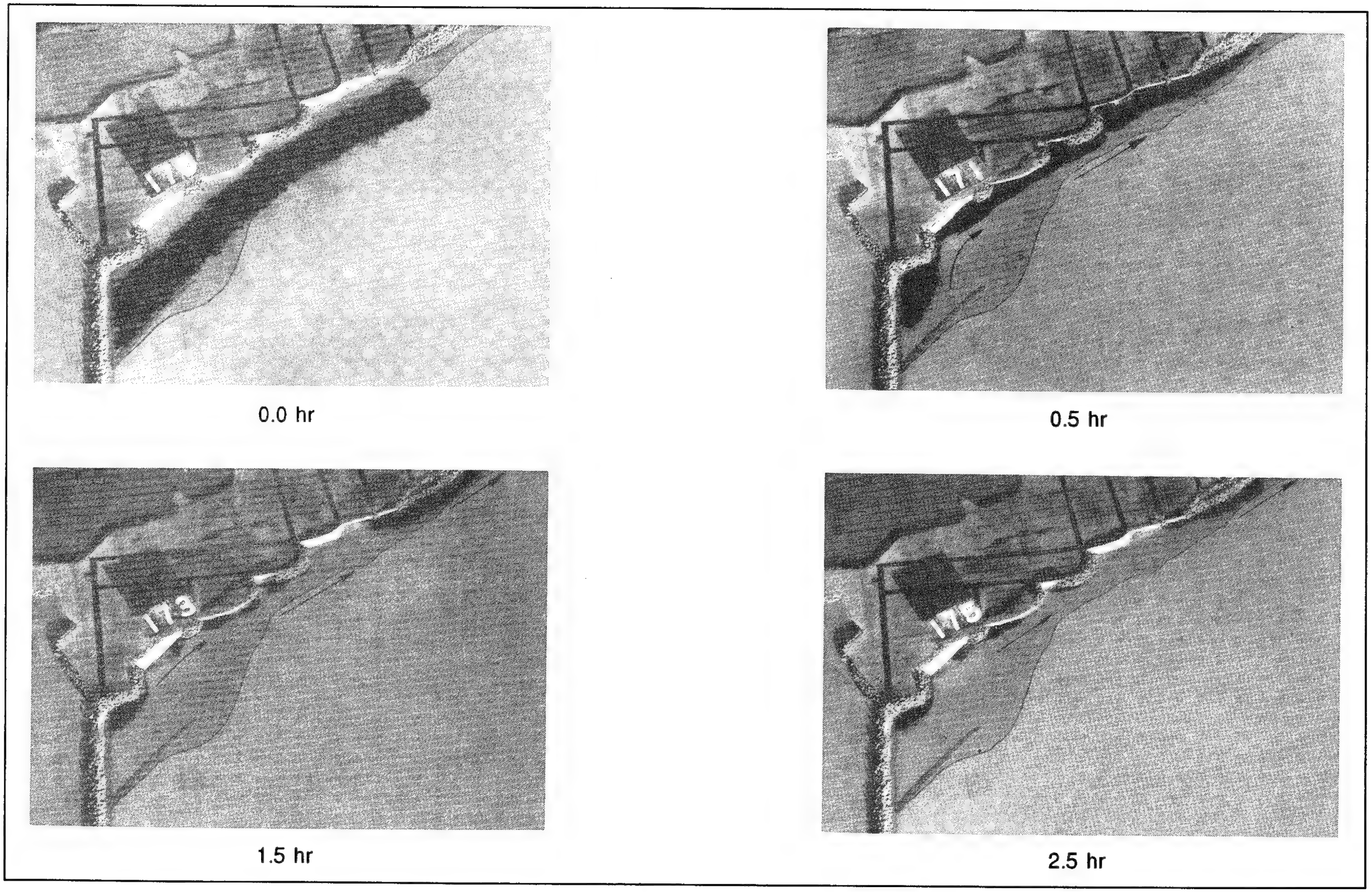


Photo 22. Progression of sediment tracer movement for existing conditions; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

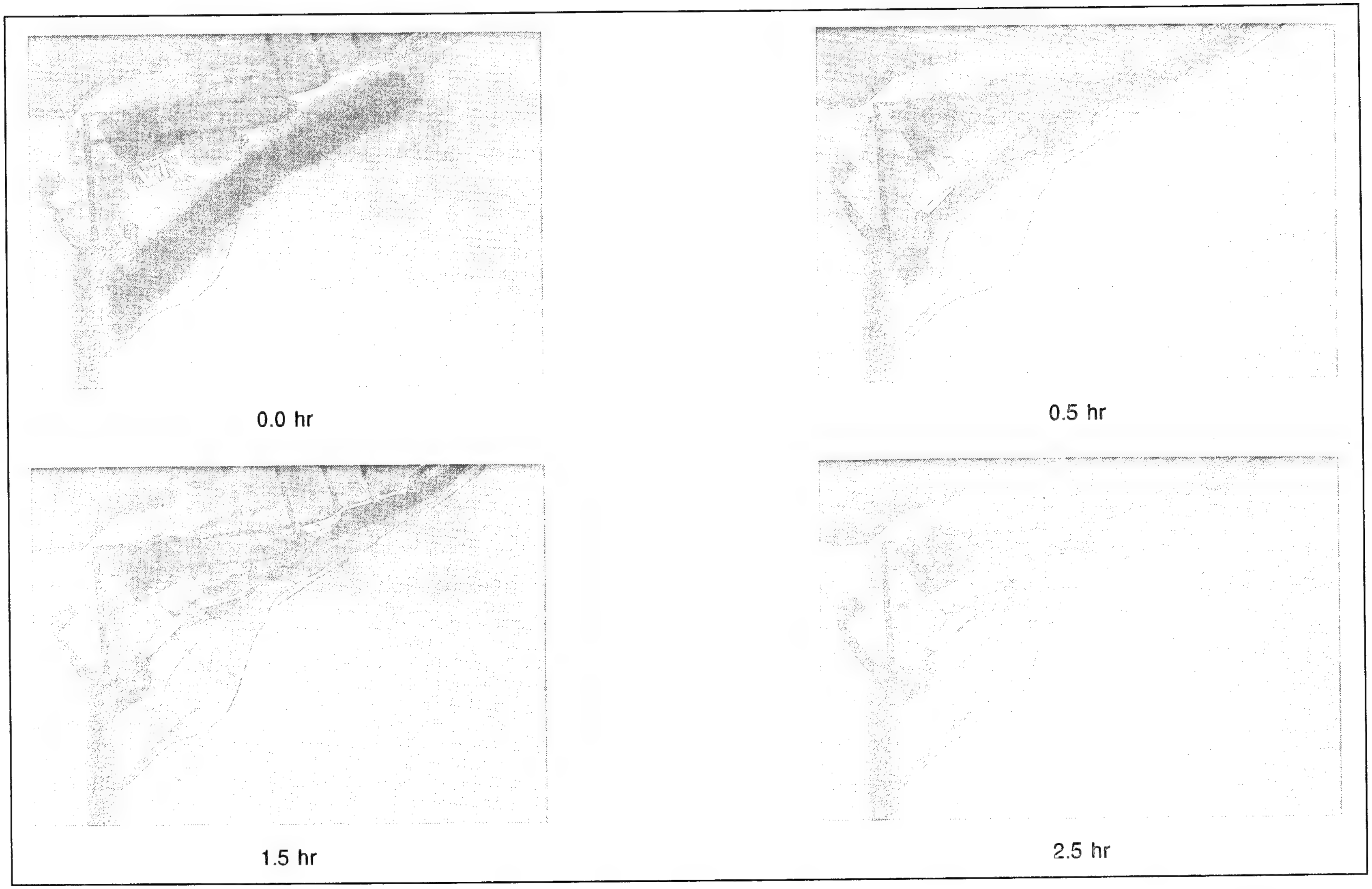
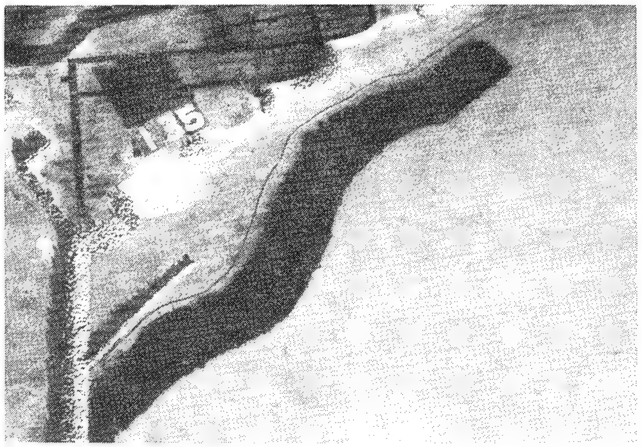
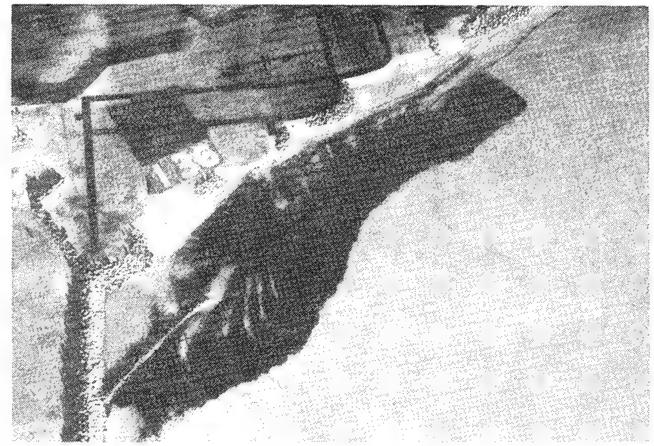


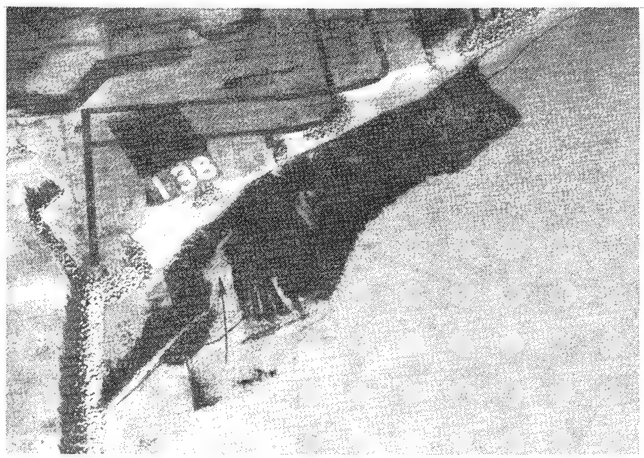
Photo 23. Progression of sediment tracer movement for existing conditions; 15-sec, 14-ft test waves from 101 deg; swl = +8.8 ft



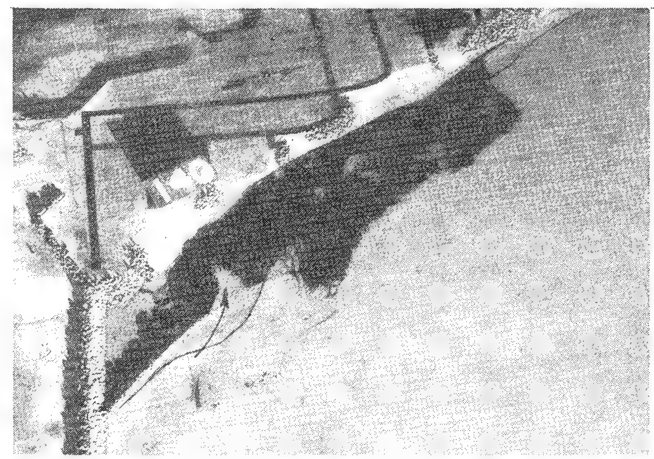
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 24. Progression of sediment tracer movement for existing conditions; 13-sec, 18-ft test waves from 88 deg; swl = 0.0 ft

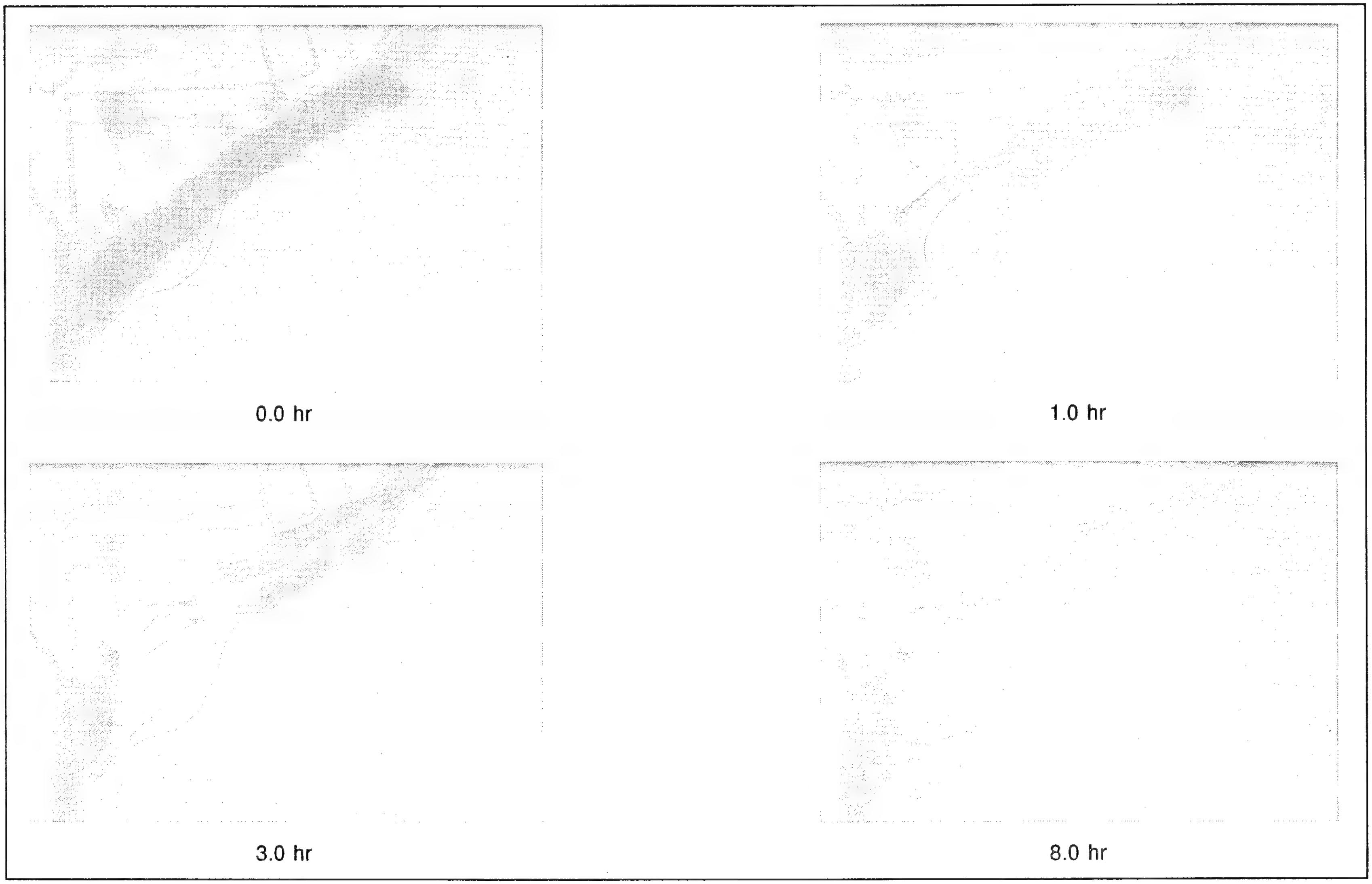
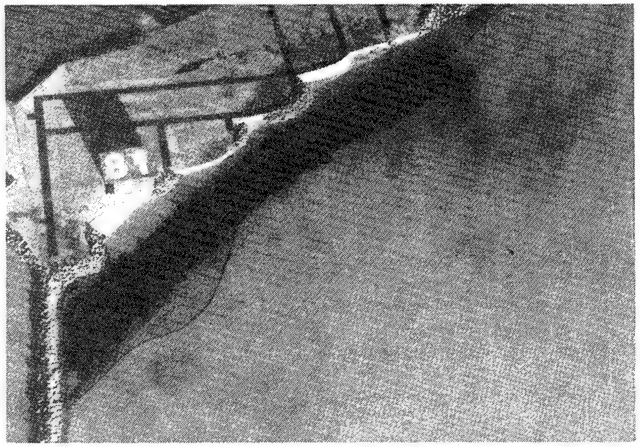
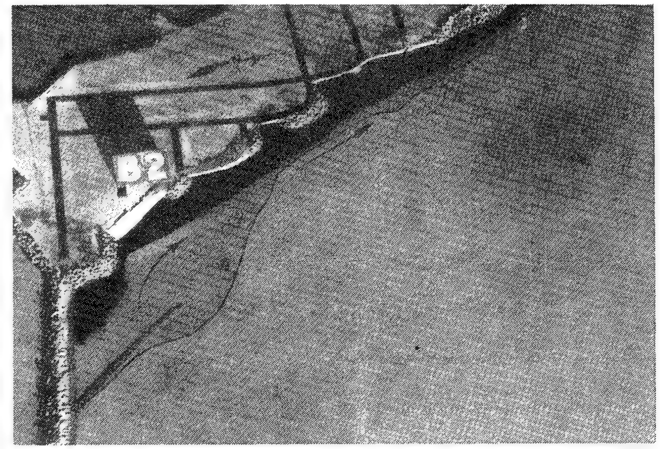


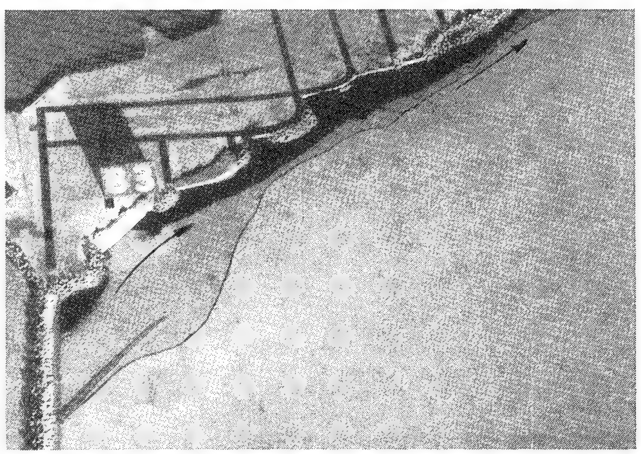
Photo 25. Progression of sediment tracer movement for existing conditions; 11-sec, 6-ft test waves from 88 deg; swl = +8.8 ft



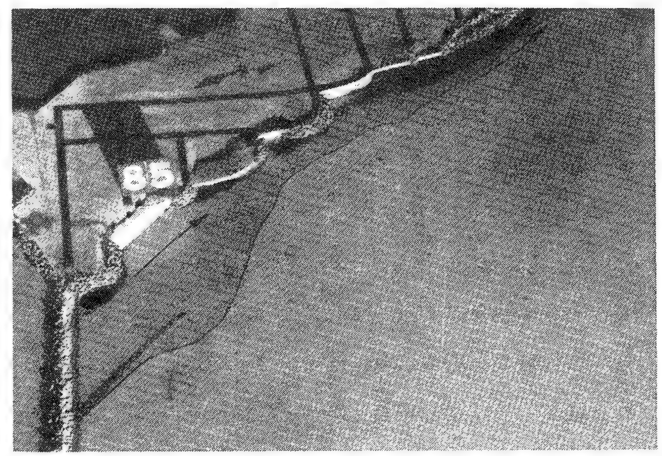
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 26. Progression of sediment tracer movement for existing conditions; 11-sec, 14-ft test waves from 88 deg; swl = +8.8 ft

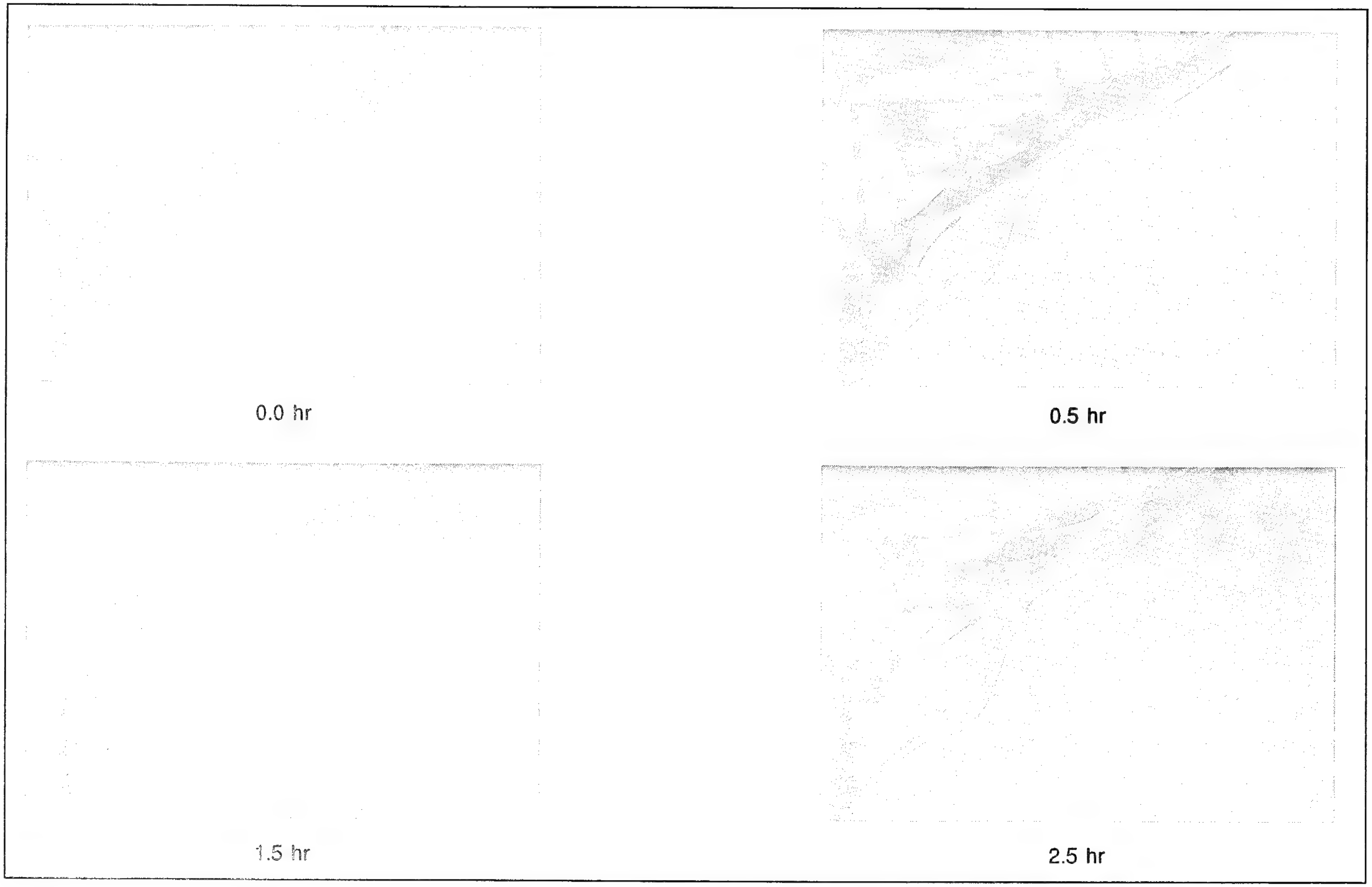
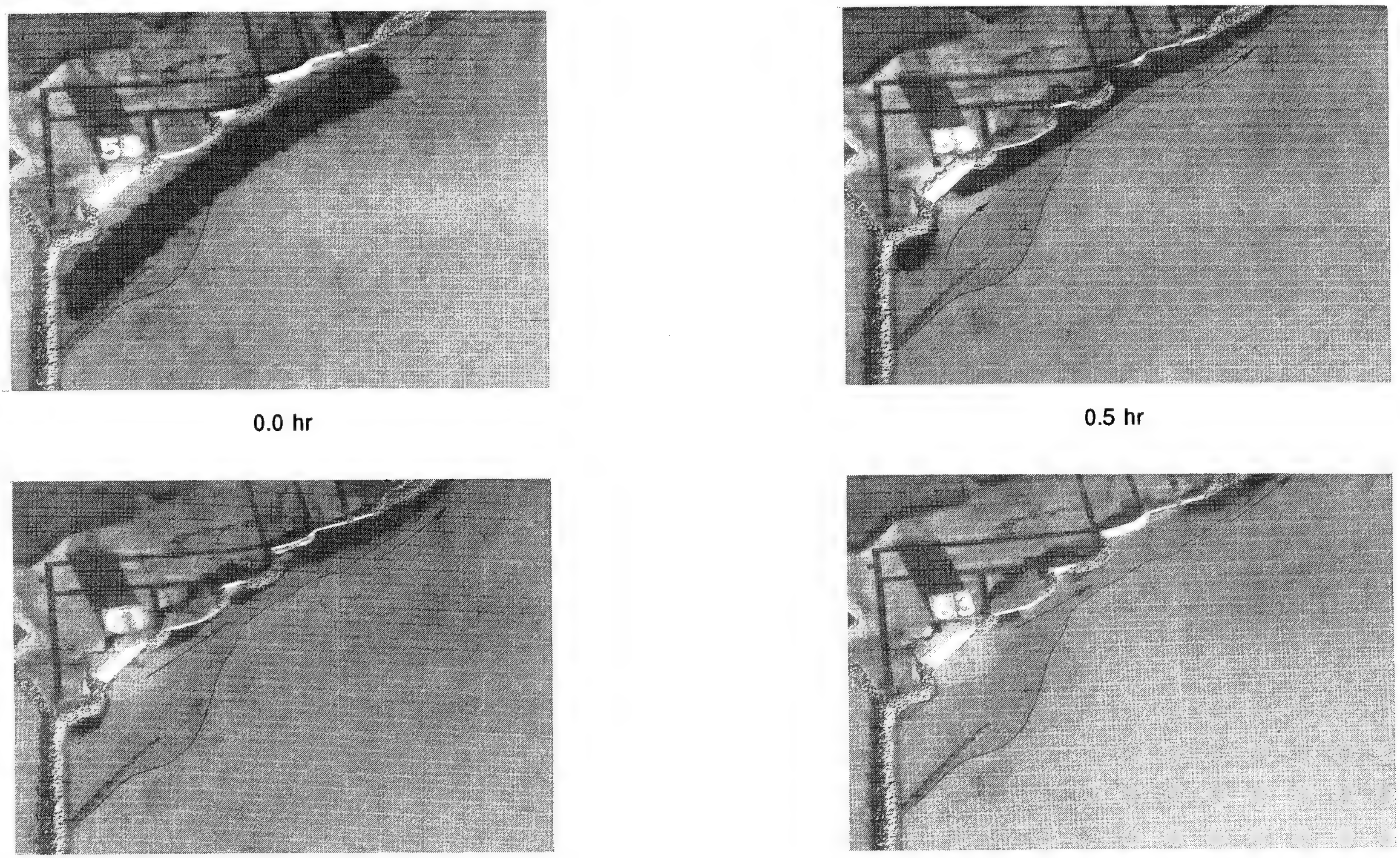


Photo 27. Progression of sediment tracer movement for existing conditions; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft


0.0 hr

0.5 hr

1.5 hr

2.5 hr

Photo 28. Progression of sediment tracer movement for existing conditions; 15-sec, 16-ft test waves from 88 deg; swl = +8.8 ft

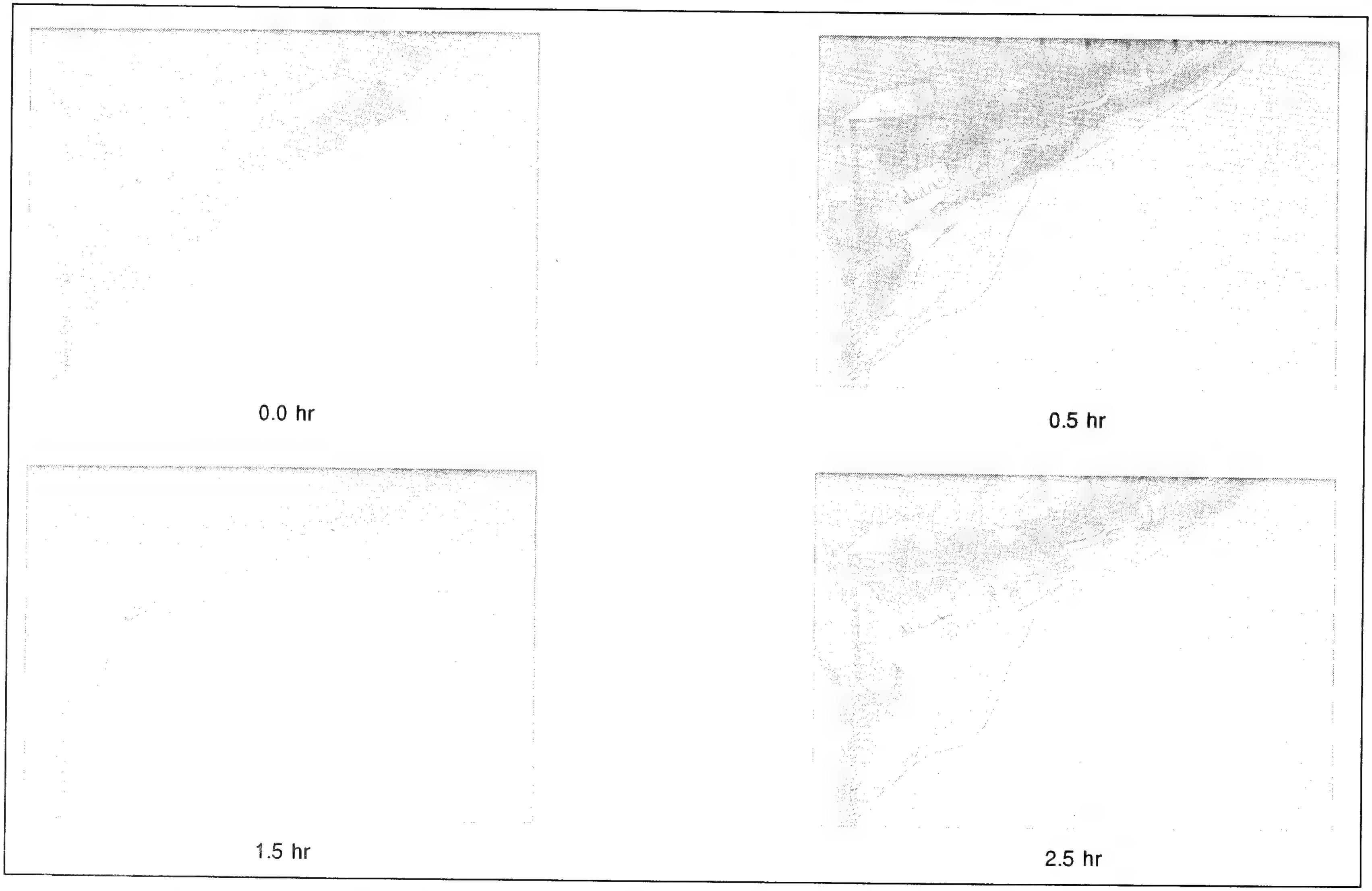


Photo 29. Progression of sediment tracer movement for existing conditions; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

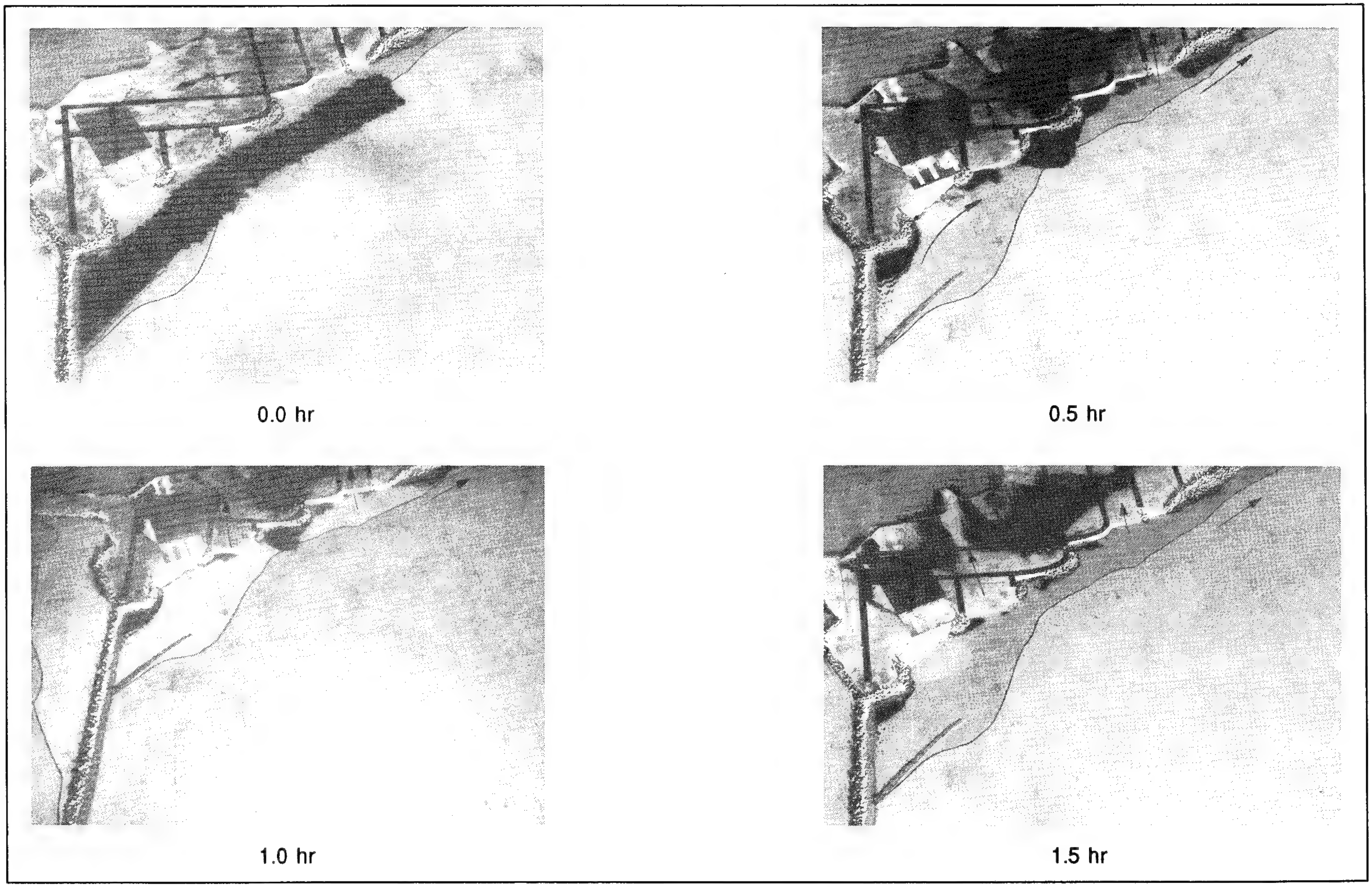


Photo 30. Progression of sediment tracer movement for existing conditions; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

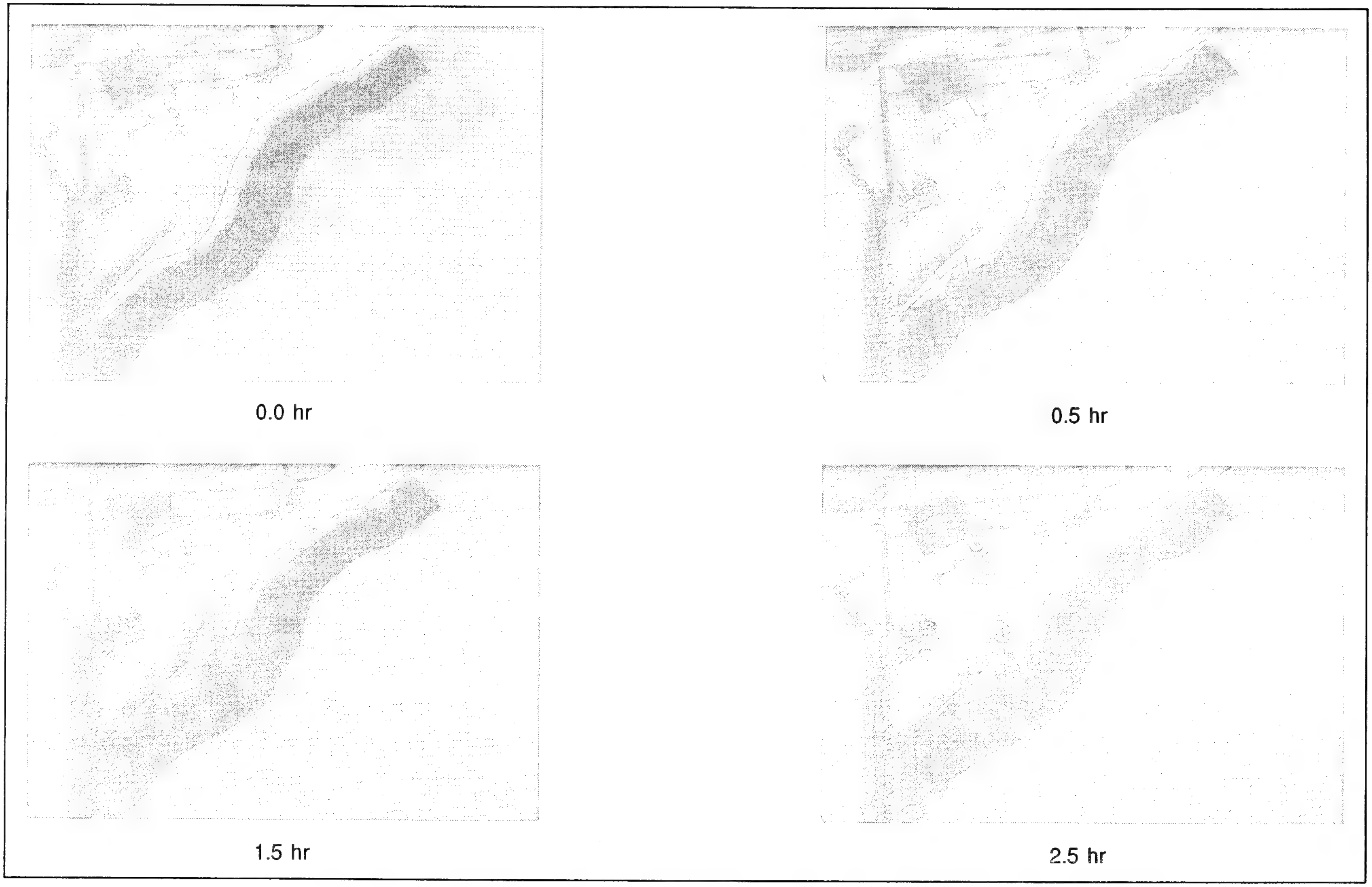
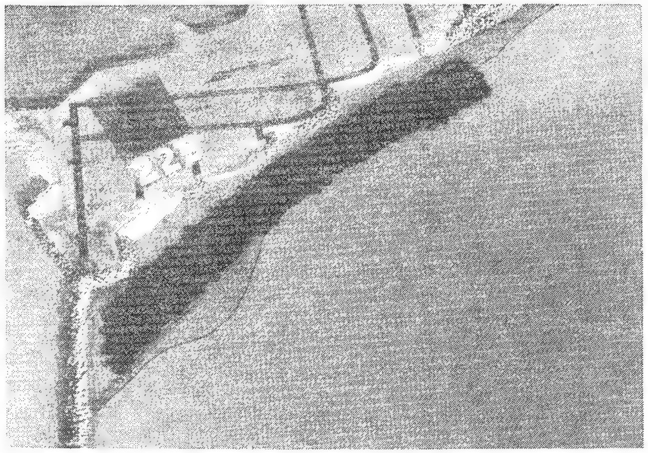
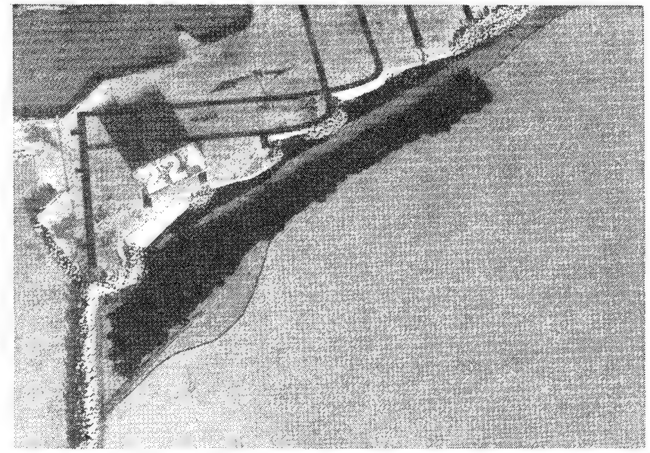


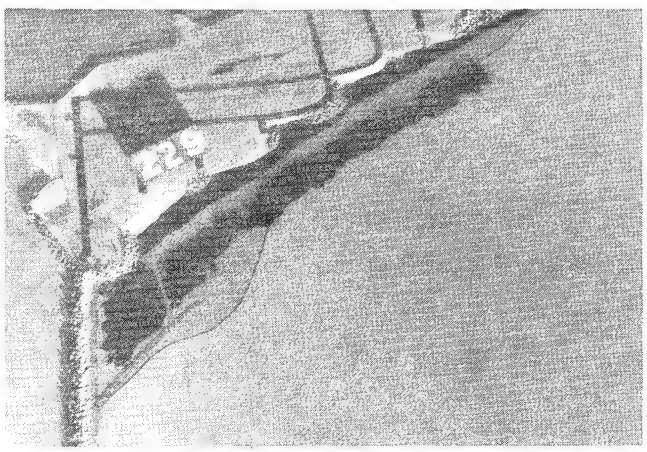
Photo 31. Progression of sediment tracer movement for existing conditions; 11-sec, 14-ft test waves from 75 deg; swl = 0.0 ft



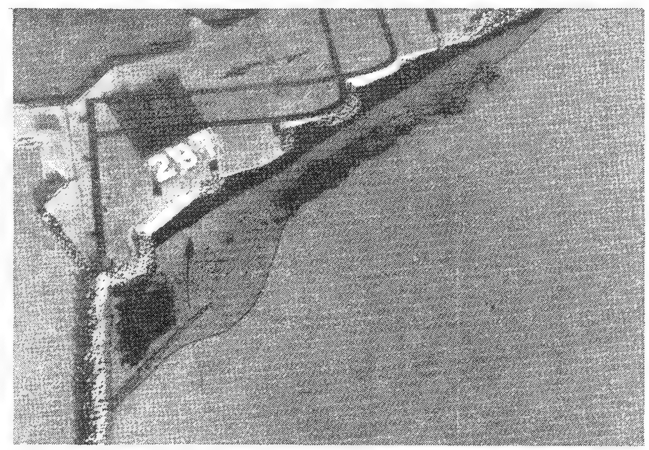
0.0 hr



1.0 hr

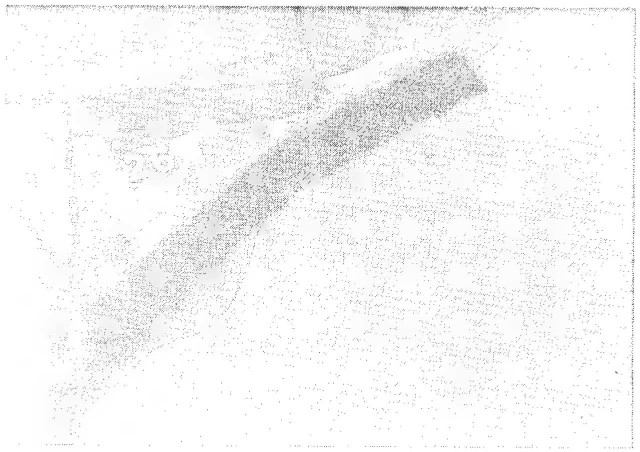


3.0 hr

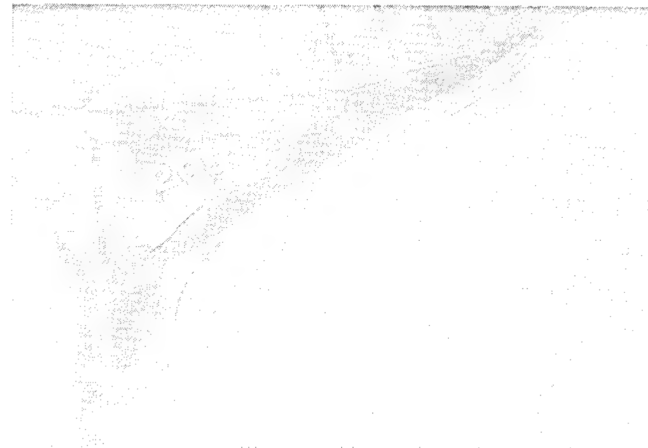


8.0 hr

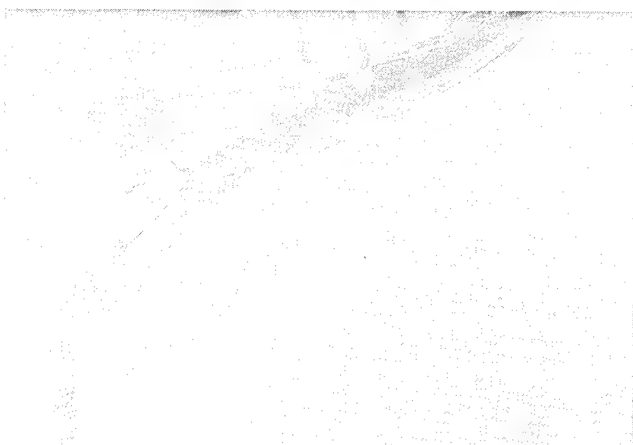
Photo 32. Progression of sediment tracer movement for existing conditions; 9-sec, 8-ft test waves from 75 deg; swl = +8.8 ft



0.0 hr



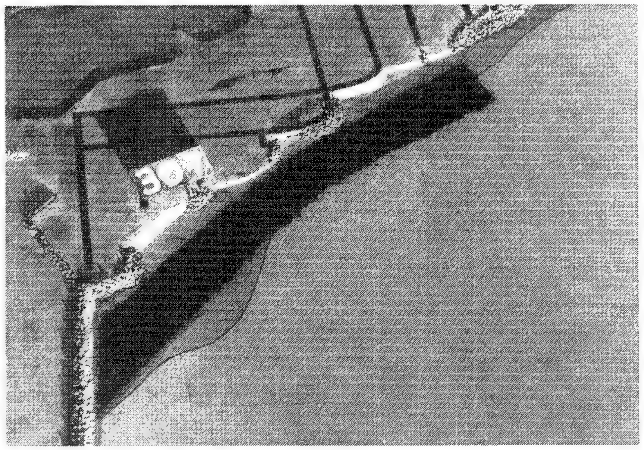
1.0 hr



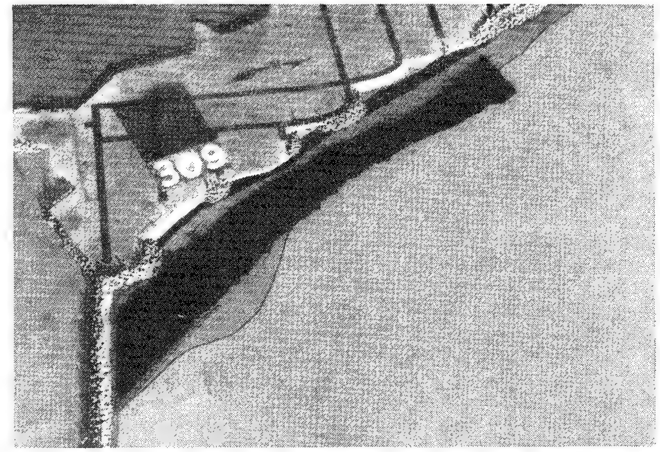
3.0 hr

6.0 hr

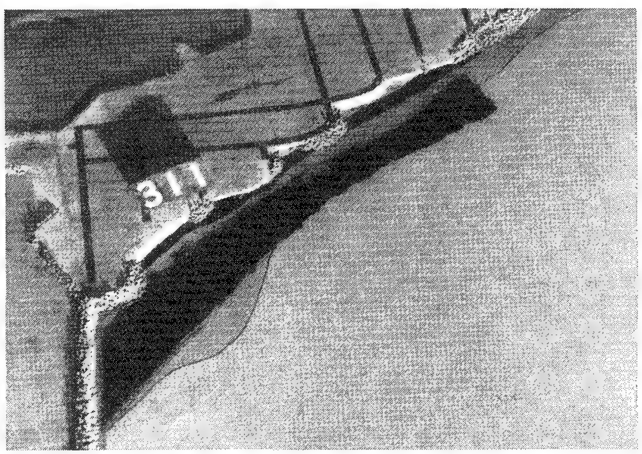
Photo 33. Progression of sediment tracer movement for existing conditions; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft



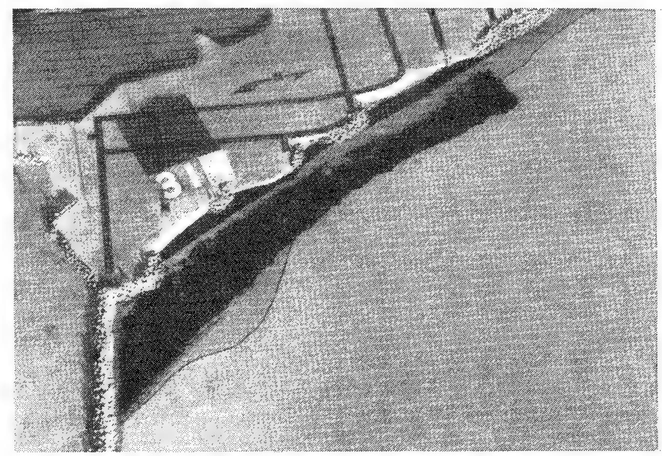
0.0 hr



2.0 hr



4.0 hr



8.0 hr

Photo 34. Progression of sediment tracer movement for existing conditions; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft

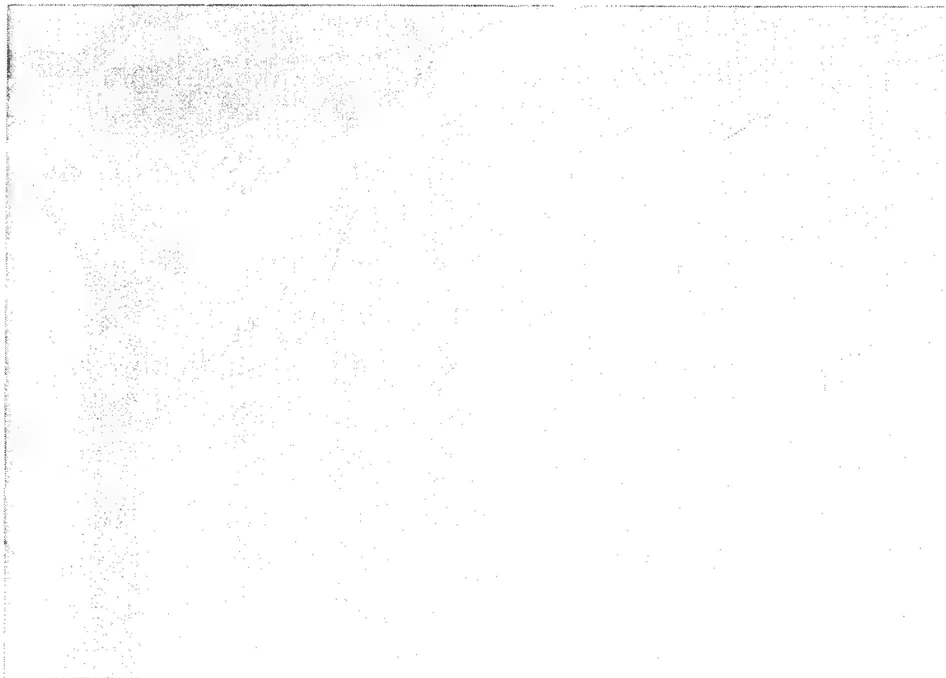


Photo 35. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 13-sec, 12-ft test waves from 101 deg; swl = 0.0 ft

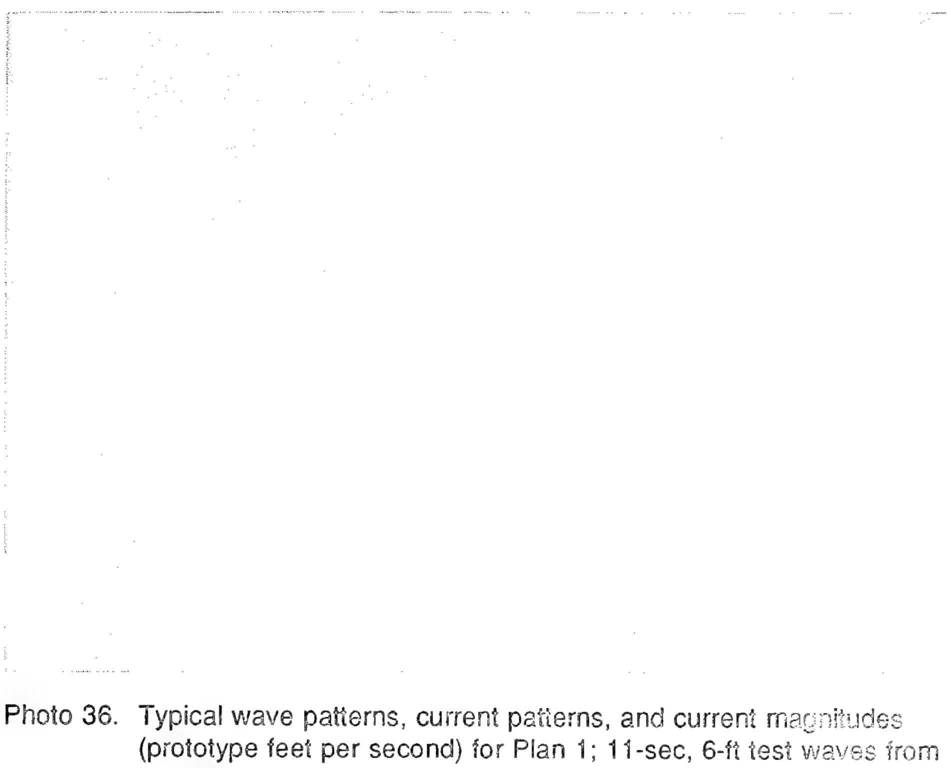


Photo 36. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 11-sec, 6-ft test waves from 101 deg; swl = +8.8 ft

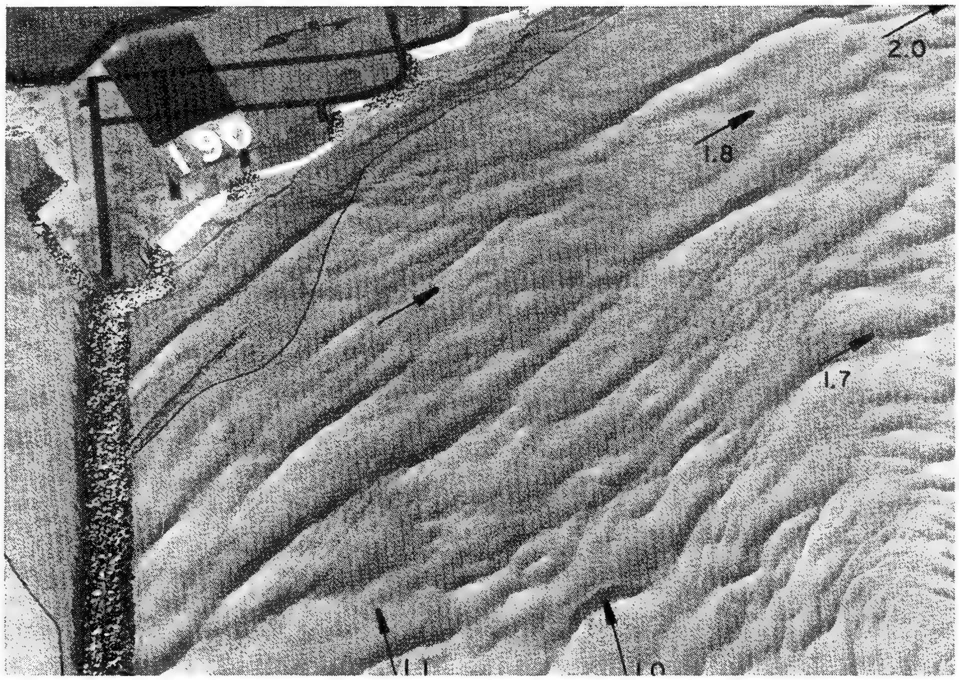


Photo 37. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

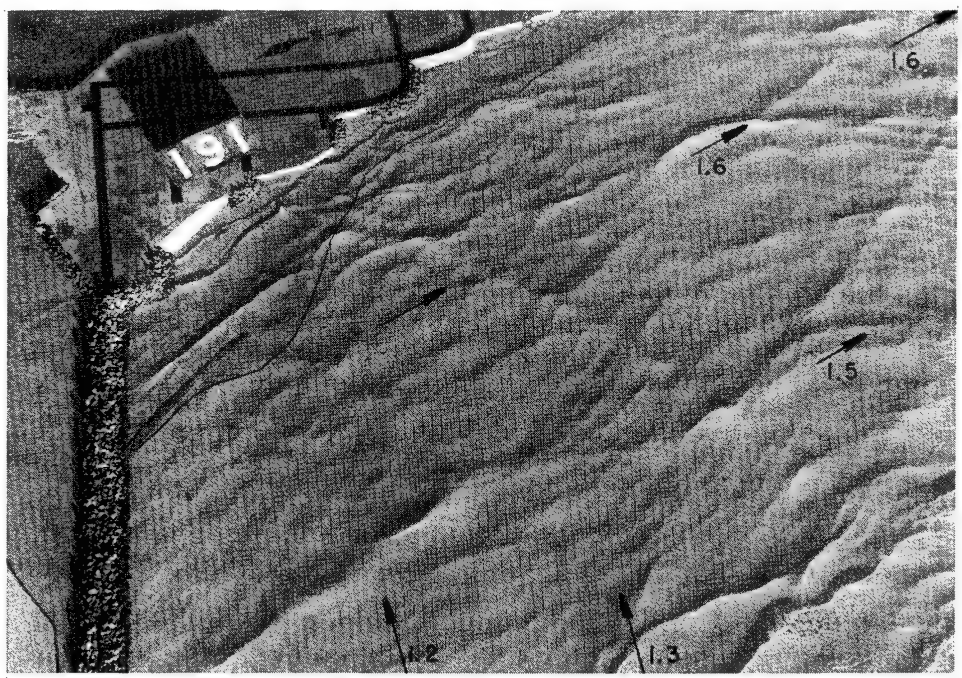


Photo 38. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 15-sec, 14-ft test waves from 101 deg; swl = +8.8 ft

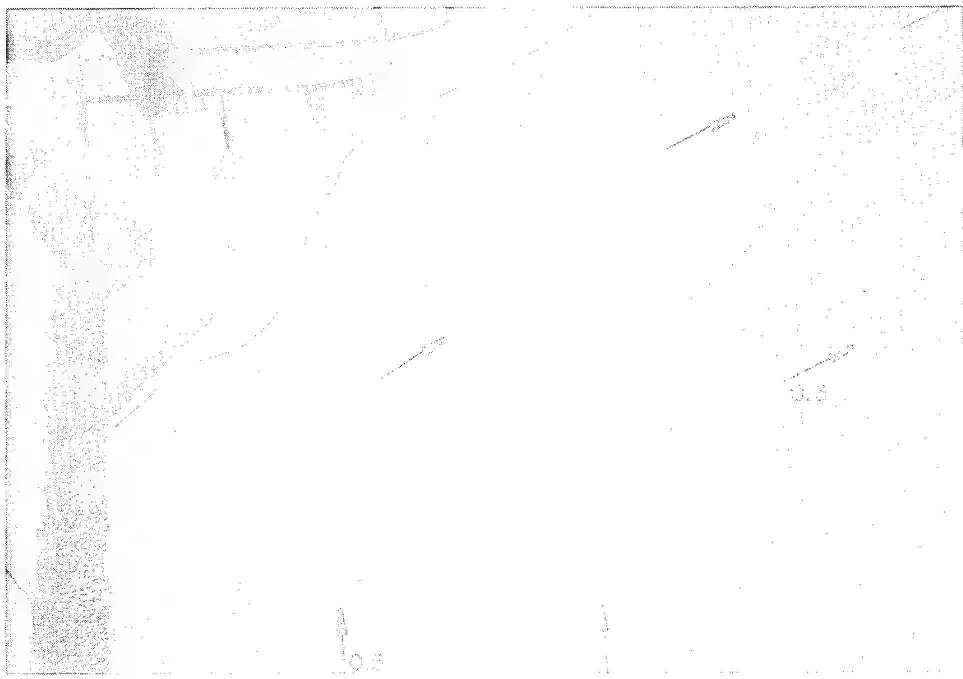


Photo 39. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 11-sec, 6-ft test waves from 88 deg; swl = 0.0 ft

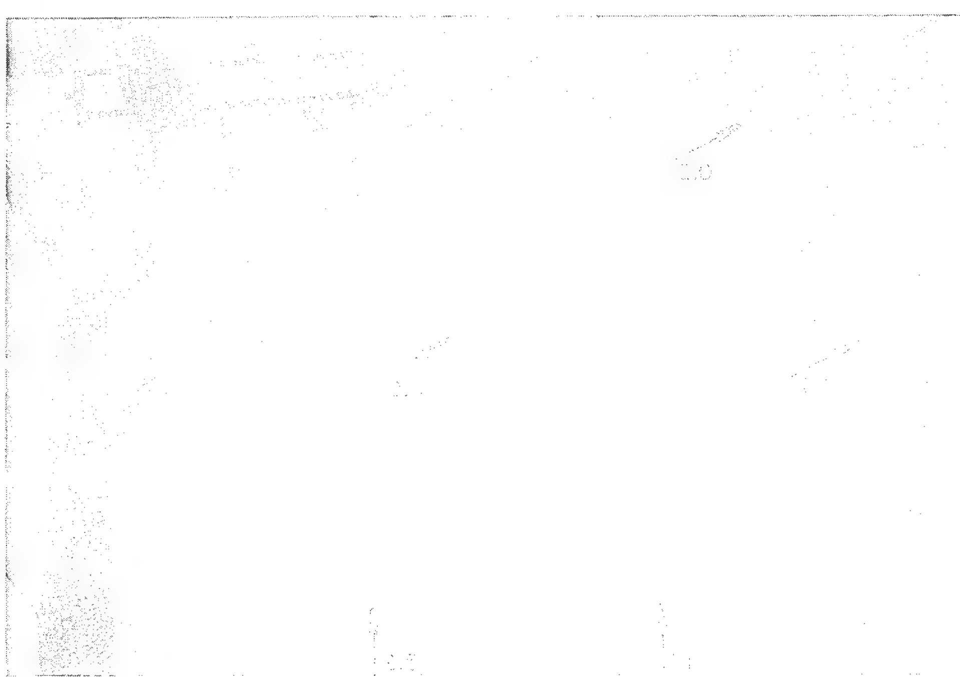


Photo 40. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 11-sec, 14-ft test waves from 88 deg; swl = 0.0 ft

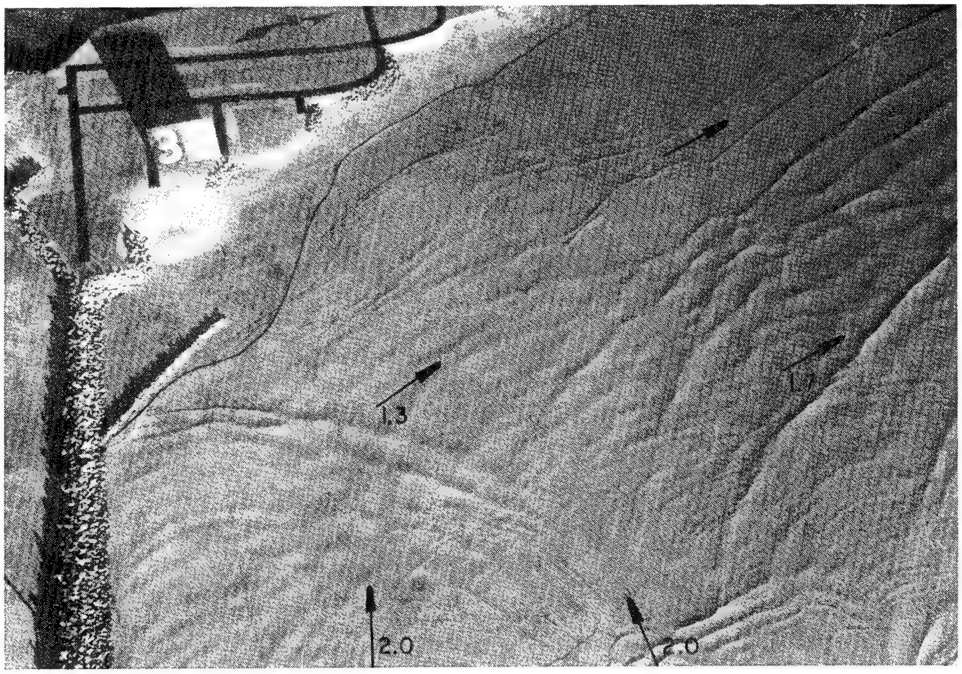


Photo 41. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 13-sec, 18-ft test waves from 88 deg; swl = 0.0 ft

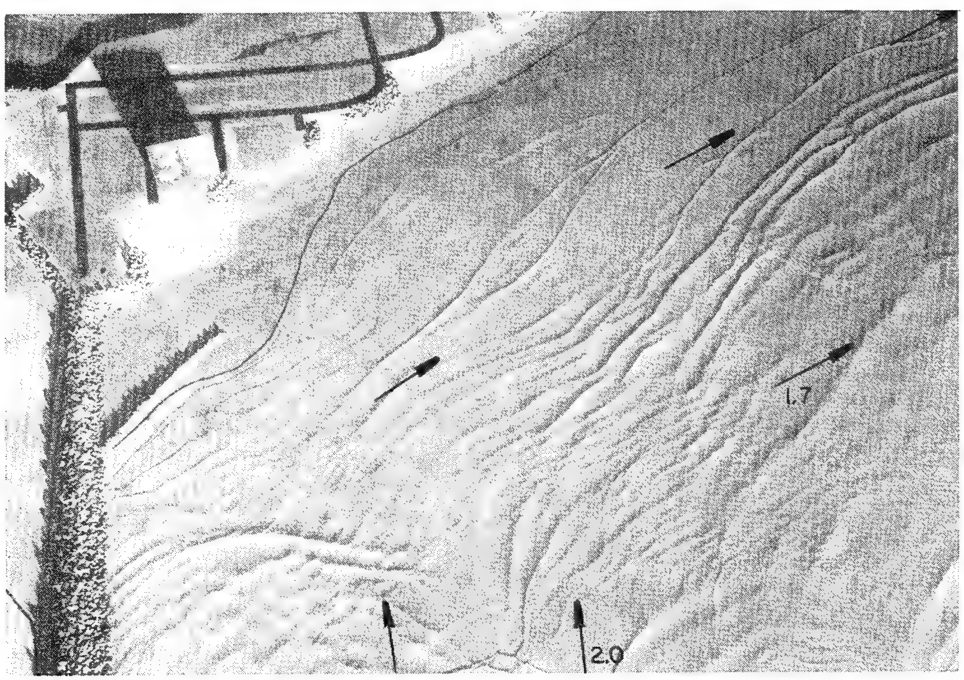


Photo 42. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 15-sec, 16-ft test waves from 88 deg; swl = 0.0 ft

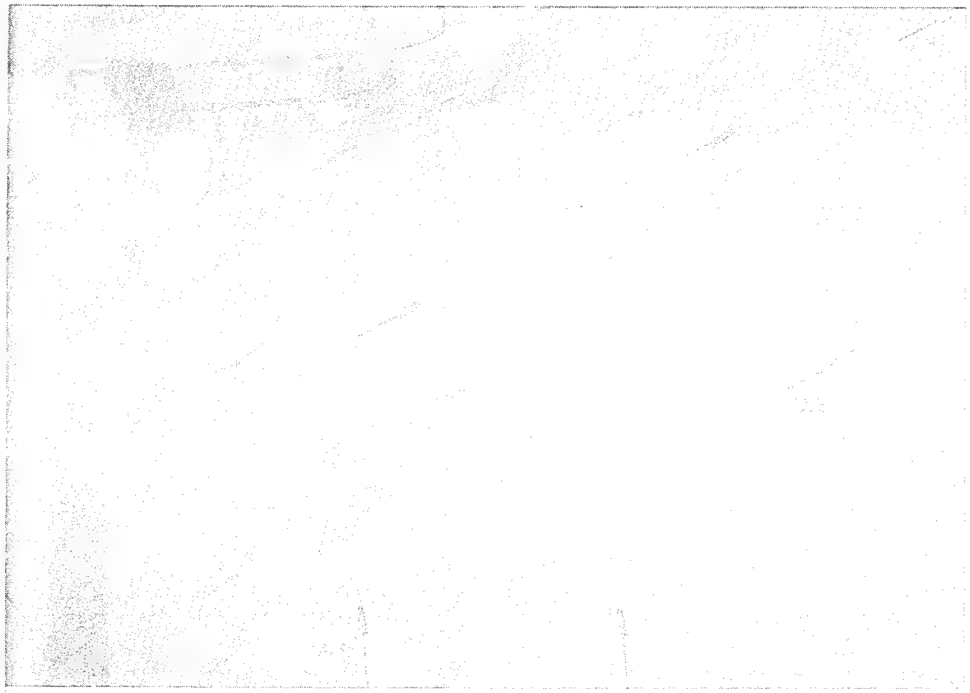


Photo 43. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 11-sec, 6-ft test waves from 88 deg; swl = +8.8 ft

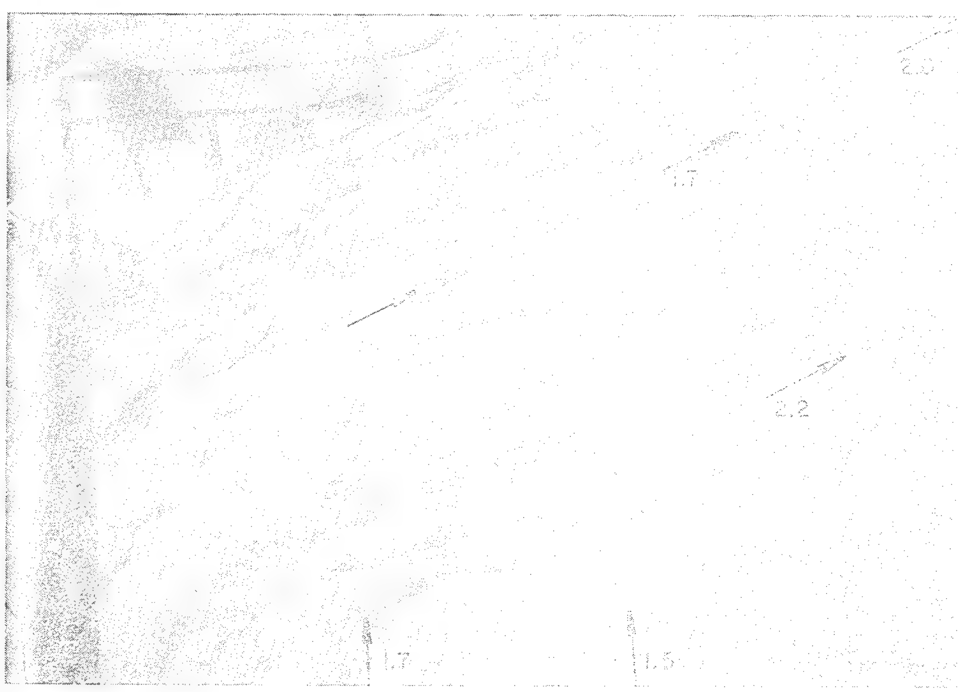


Photo 44. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 11-sec, 14-ft test waves from 88 deg; swl = +8.8 ft

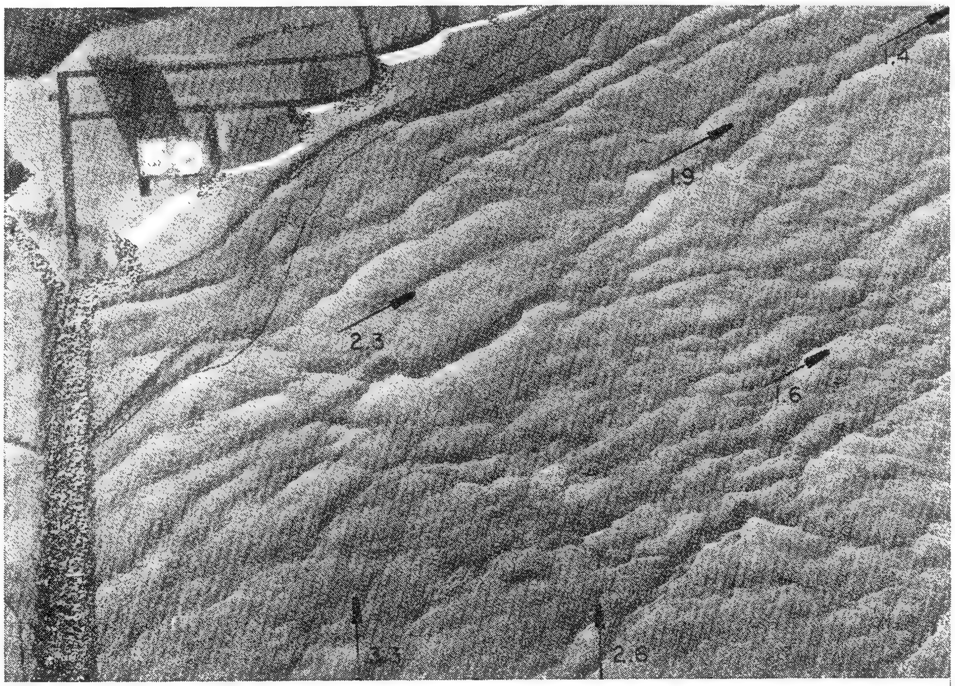


Photo 45. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft

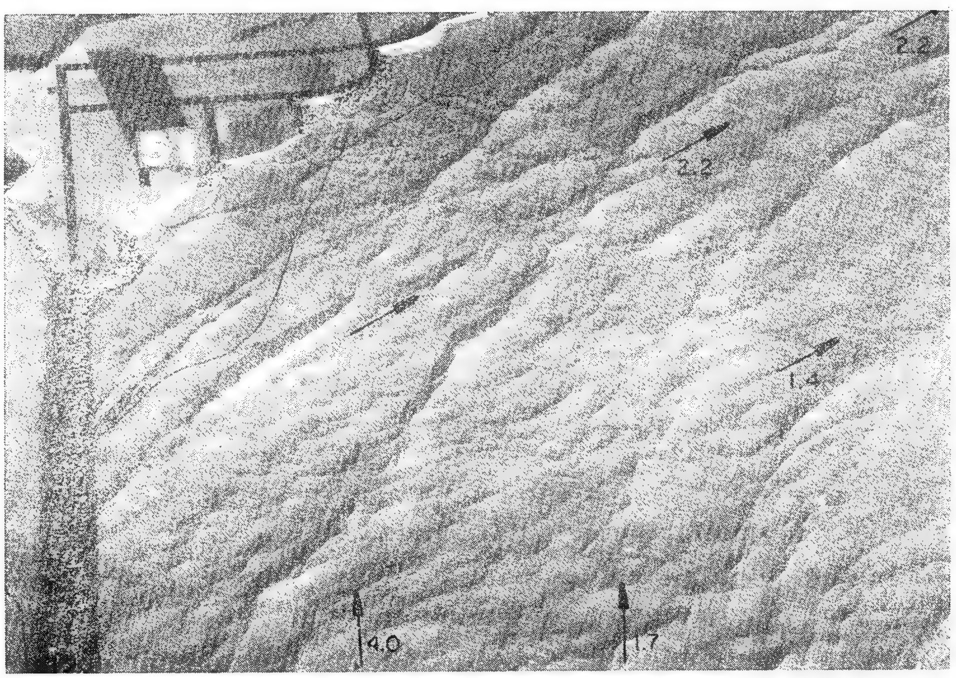


Photo 46. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 15-sec, 16-ft test waves from 88 deg; swl = +8.8 ft

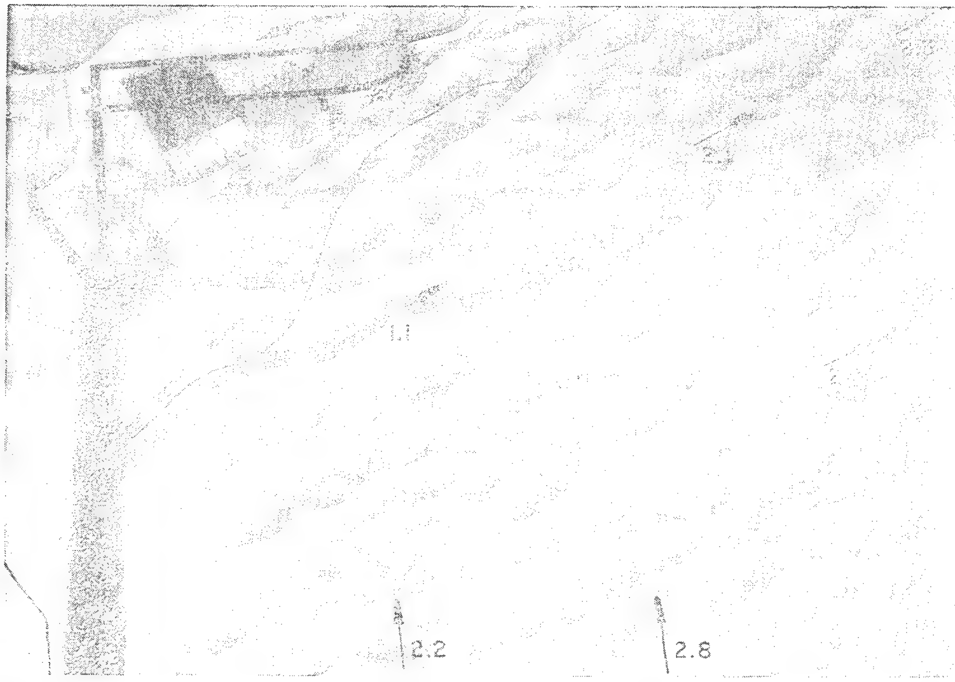


Photo 47. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

Photo 48. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

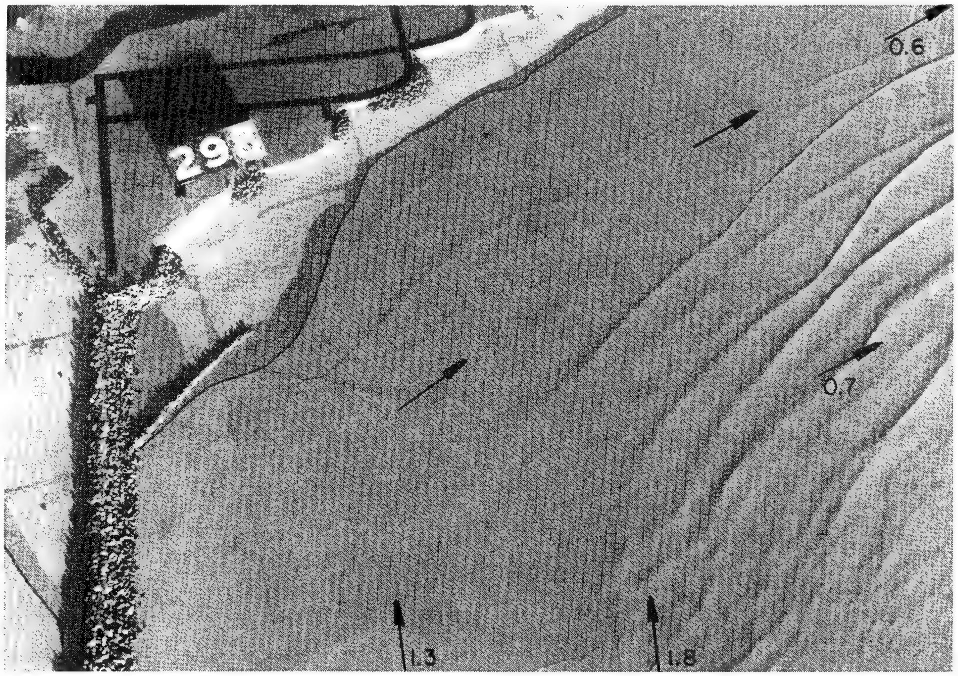


Photo 49. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 11-sec, 14-ft test waves from 75 deg; swl = 0.0 ft

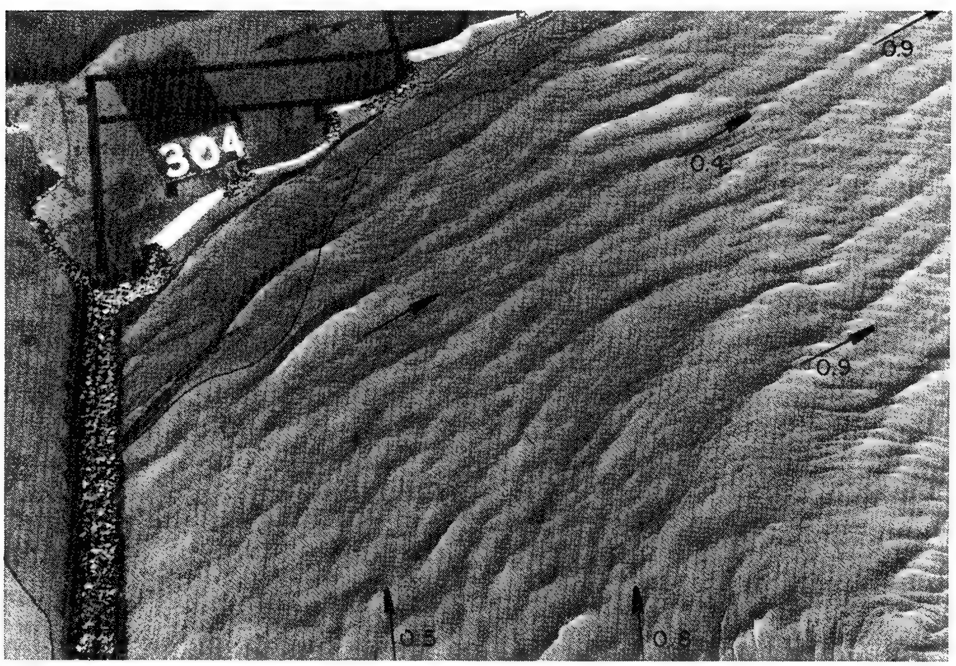


Photo 50. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 9-sec, 8-ft test waves from 75 deg; swl = +8.8 ft

Photo 51. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft

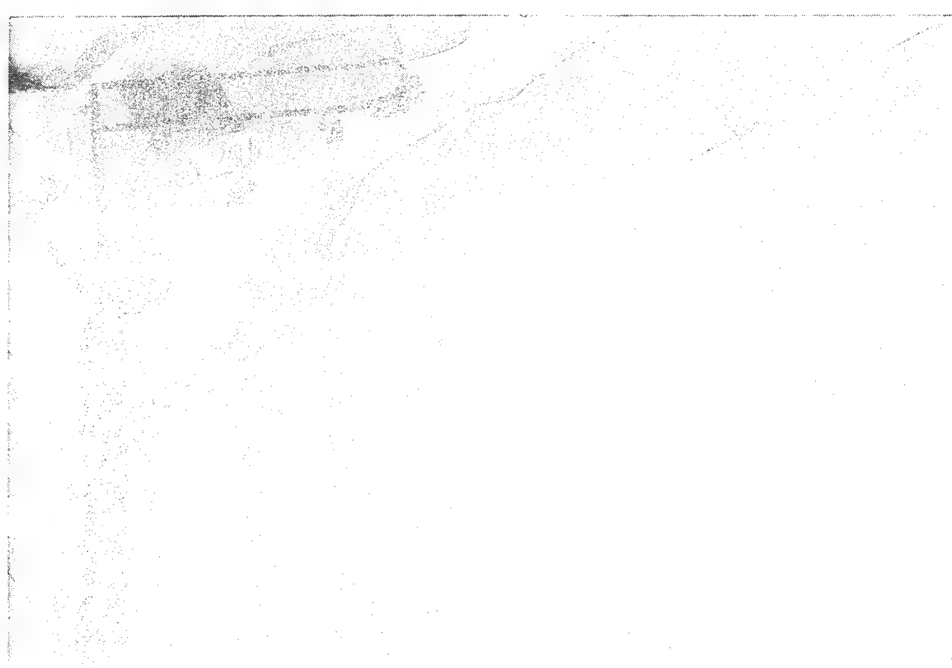


Photo 52. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 7-sec, 4-ft test waves from 56 deg; swl = 0.0 ft

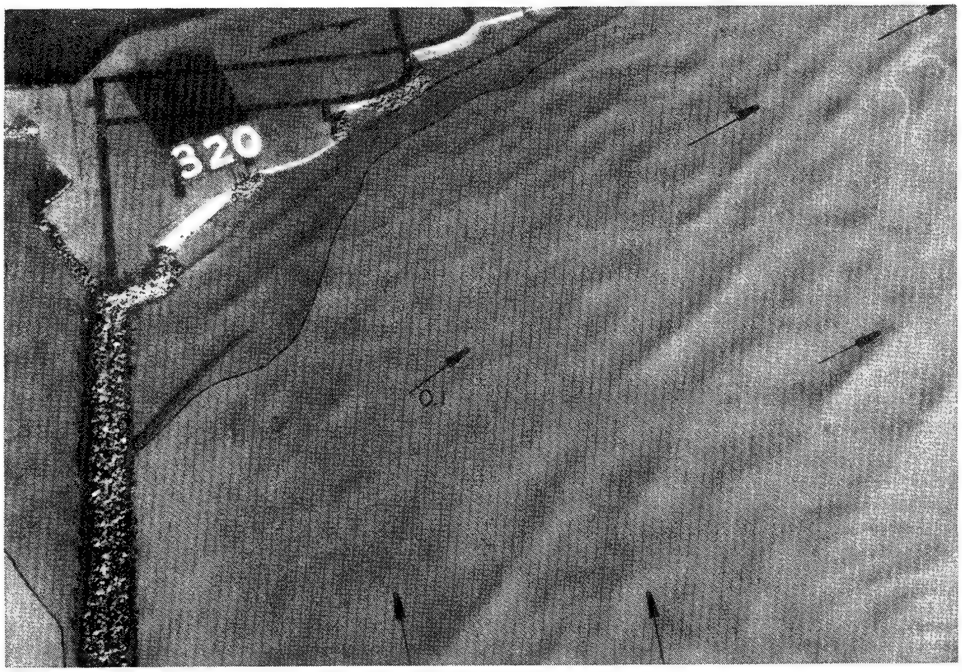


Photo 53. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 1; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft

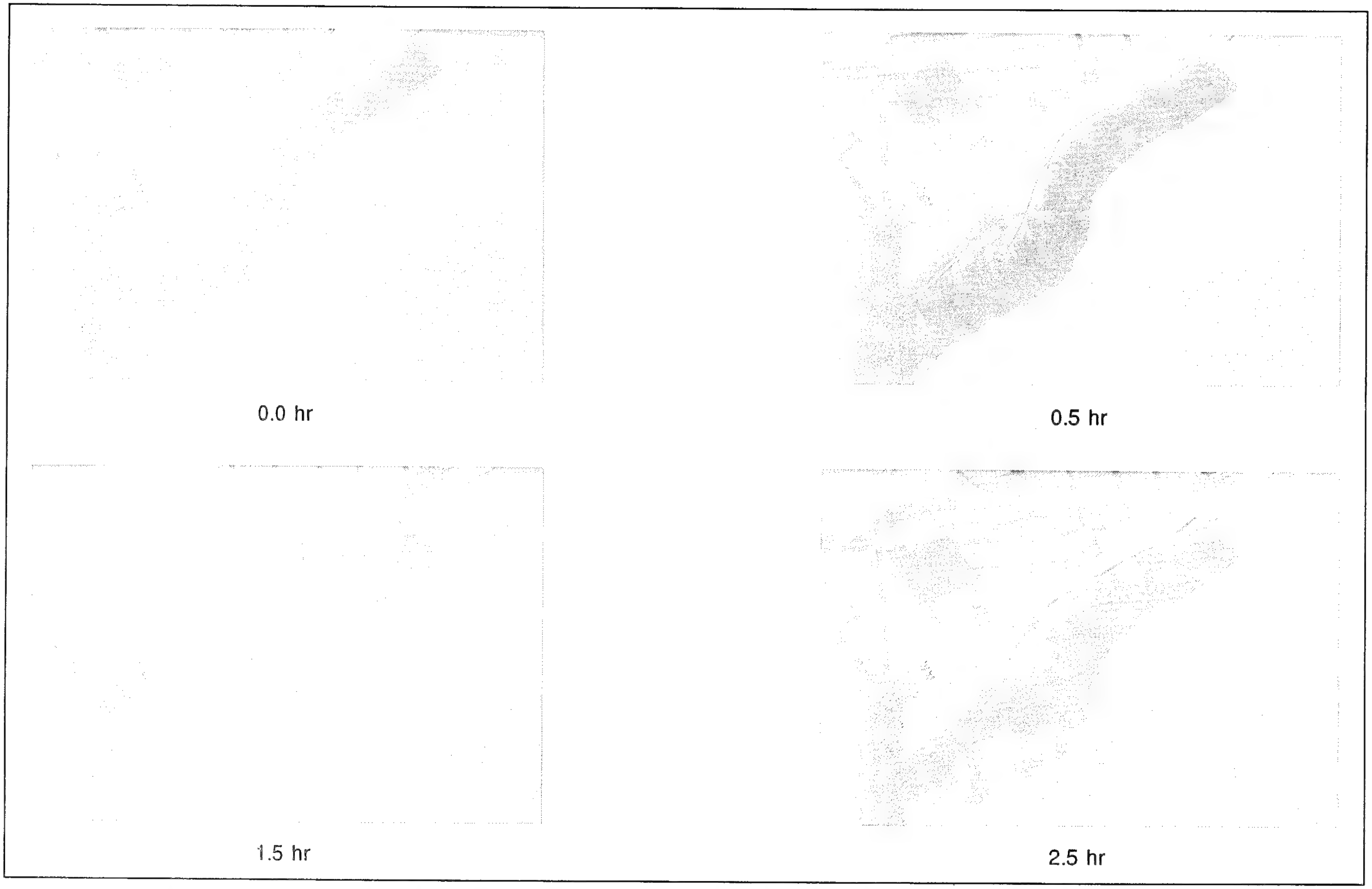


Photo 54. Progression of sediment tracer movement for Plan 1; 13-sec, 12-ft test waves from 101 deg; swl = 0.0 ft

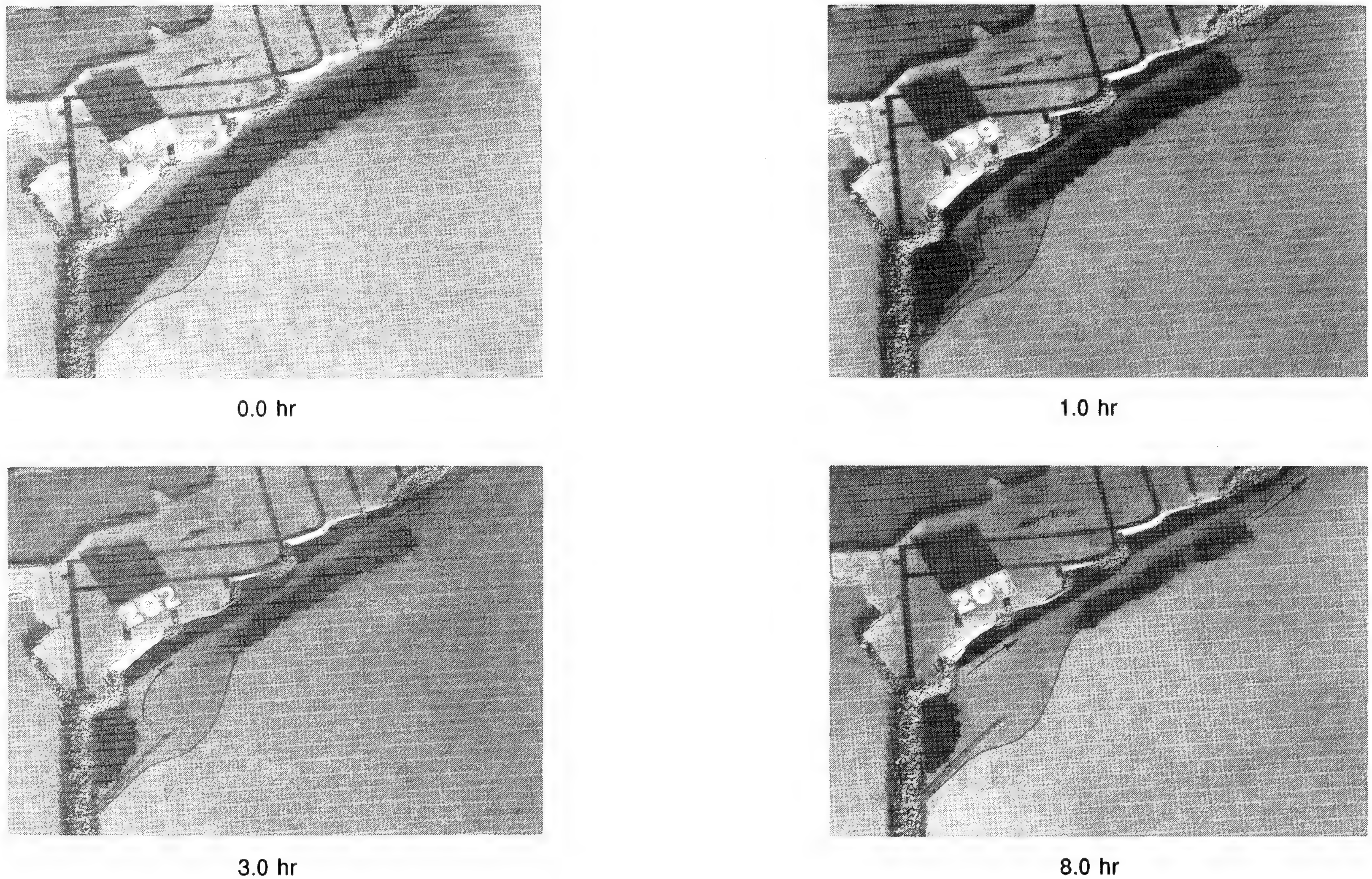


Photo 55. Progression of sediment tracer movement for Plan 1; 11-sec, 6-ft test waves from 101 deg; swl = +8.8 ft

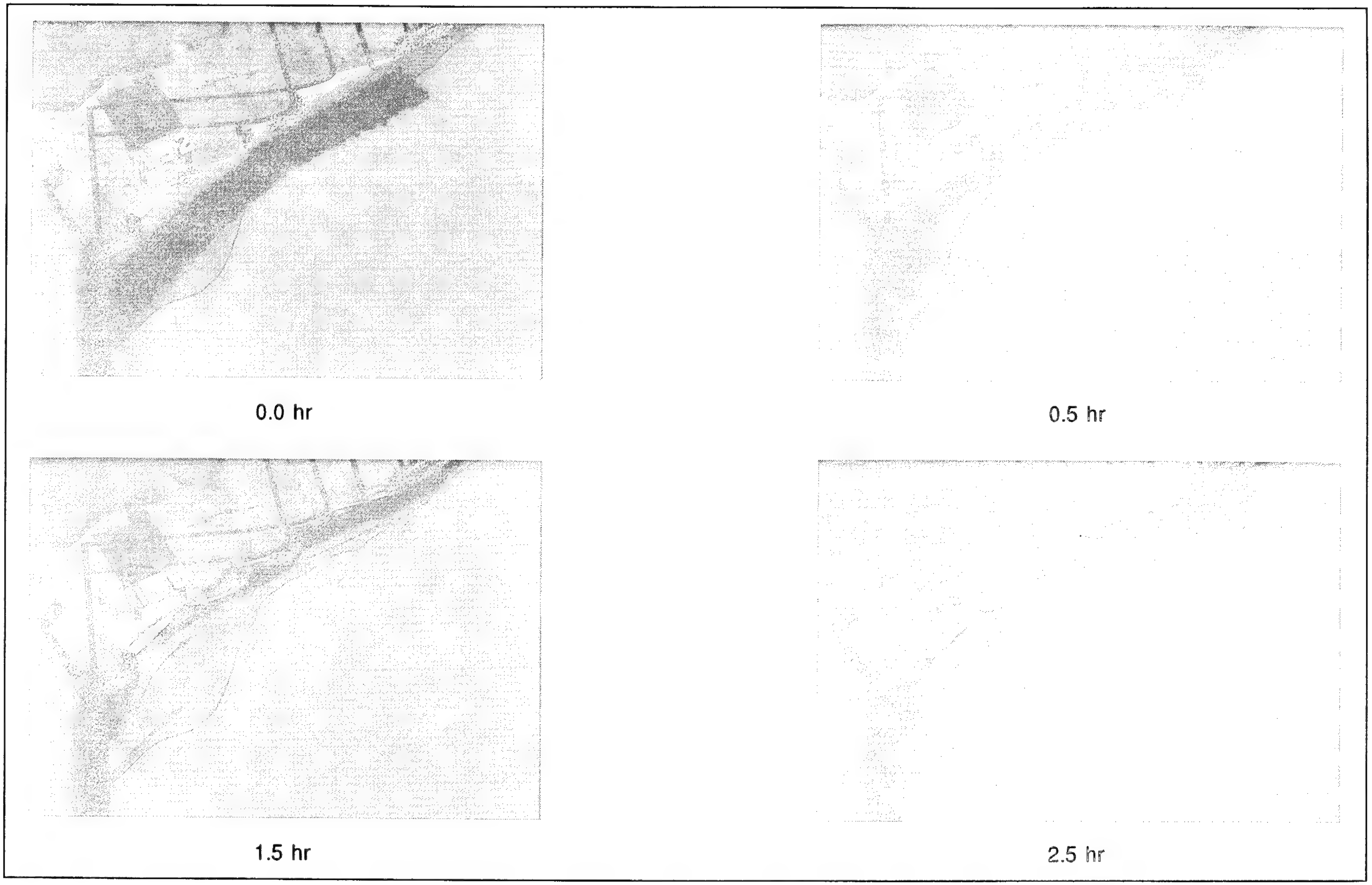
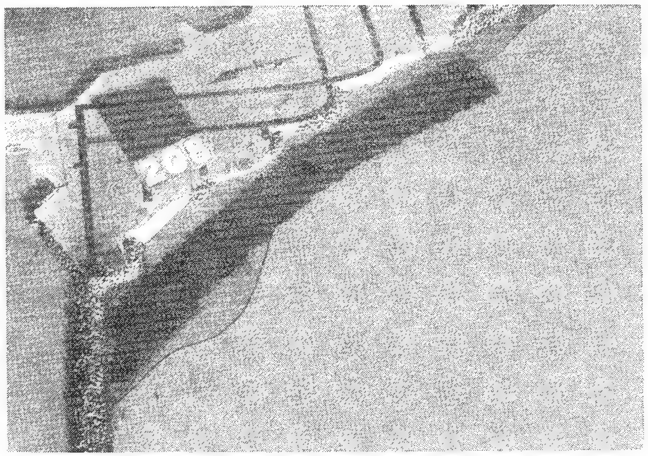
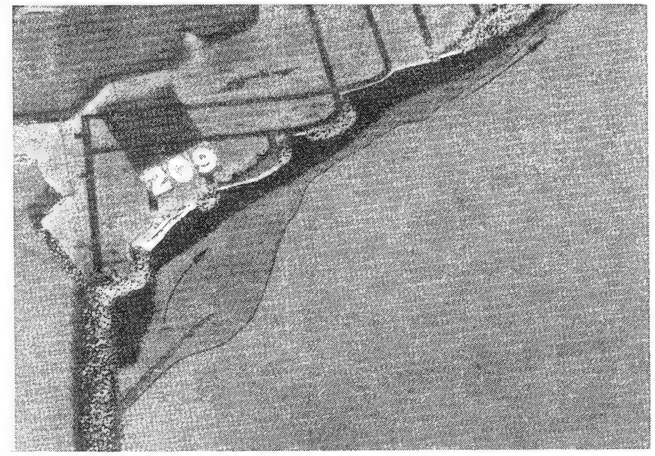


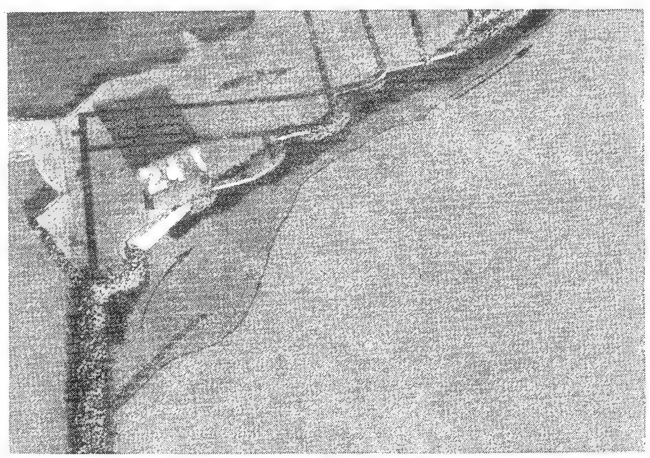
Photo 56. Progression of sediment tracer movement for Plan 1; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft



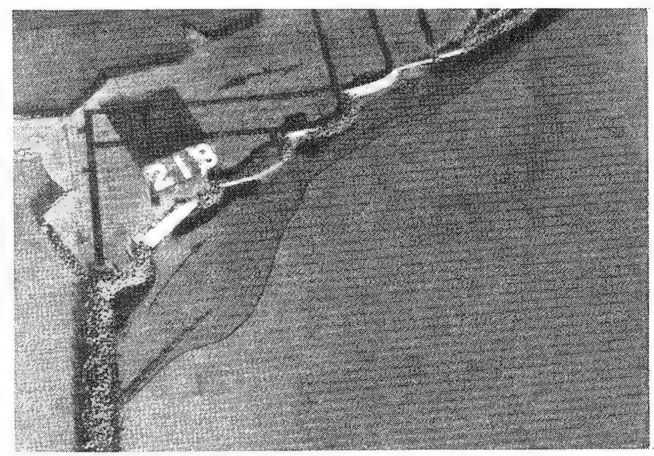
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 57. Progression of sediment tracer movement for Plan 1; 15-sec, 14-ft test waves from 101 deg; swl = +8.8 ft

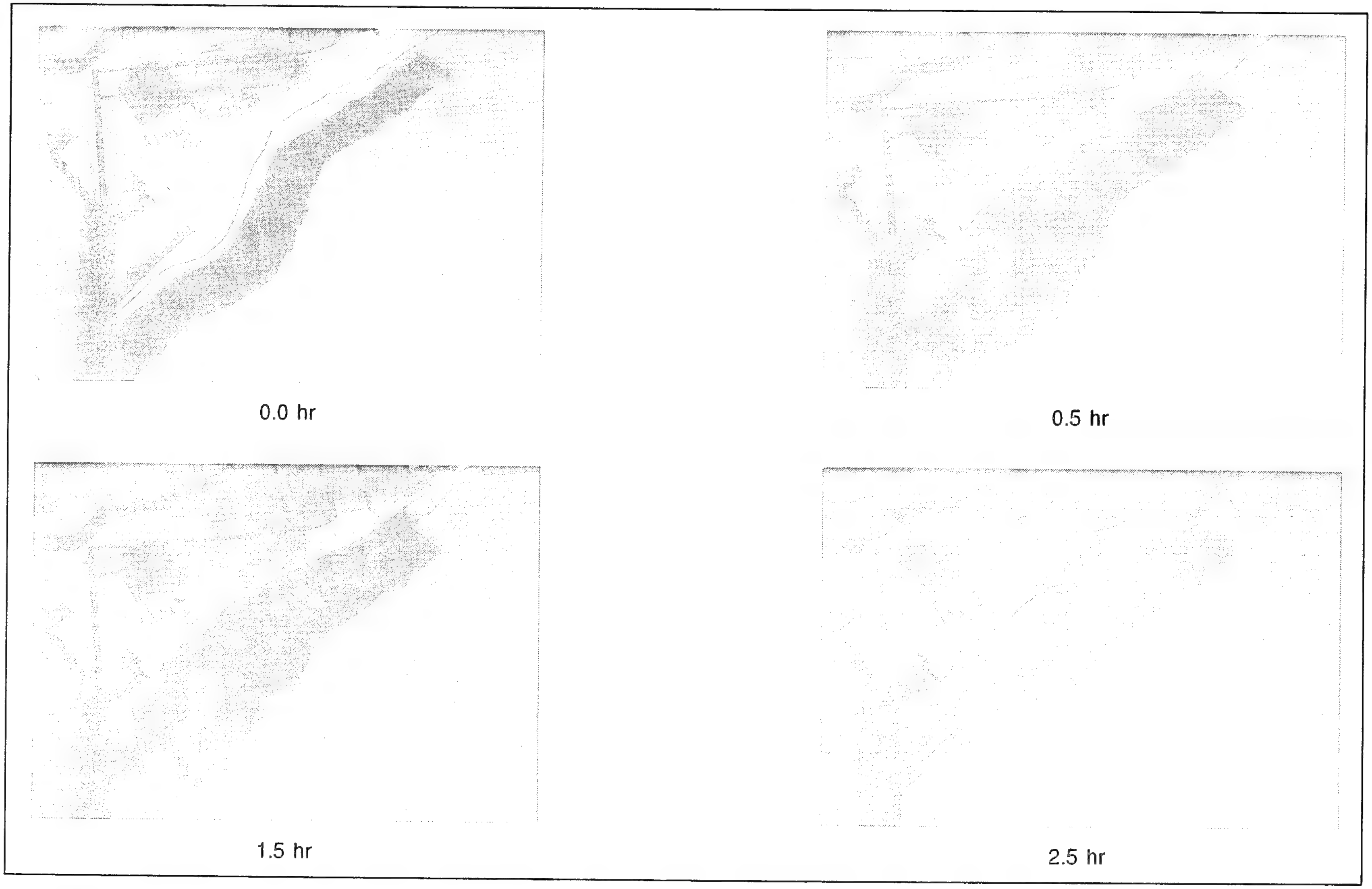
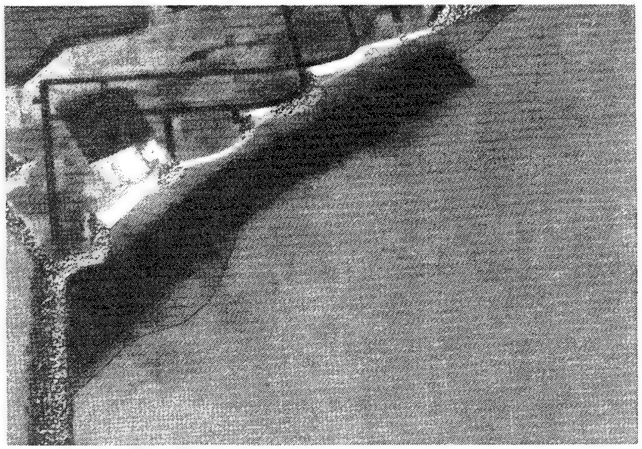
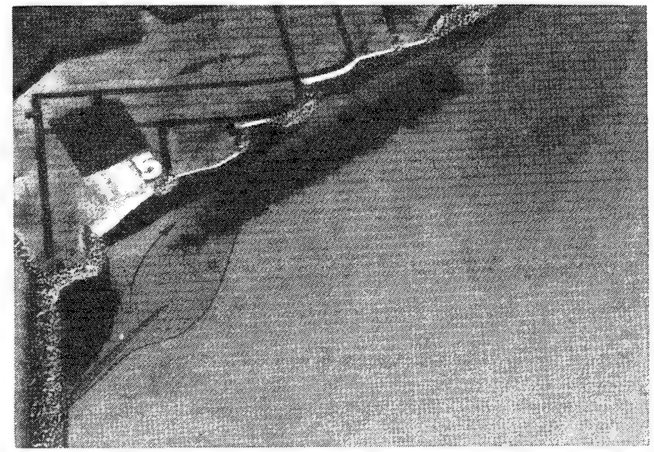


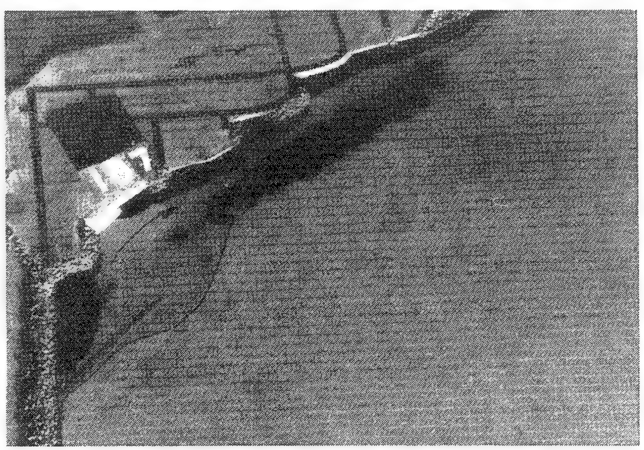
Photo 58. Progression of sediment tracer movement for Plan 1; 13-sec, 18-ft test waves from 88 deg; swl = 0.0 ft



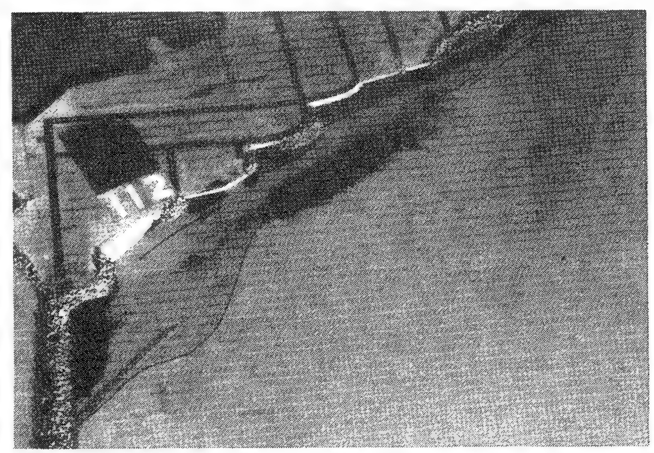
0.0 hr



1.0 hr



3.0 hr



8.0 hr

Photo 59. Progression of sediment tracer movement for Plan 1; 11-sec, 6-ft test waves from 88 deg; swl = +8.8 ft

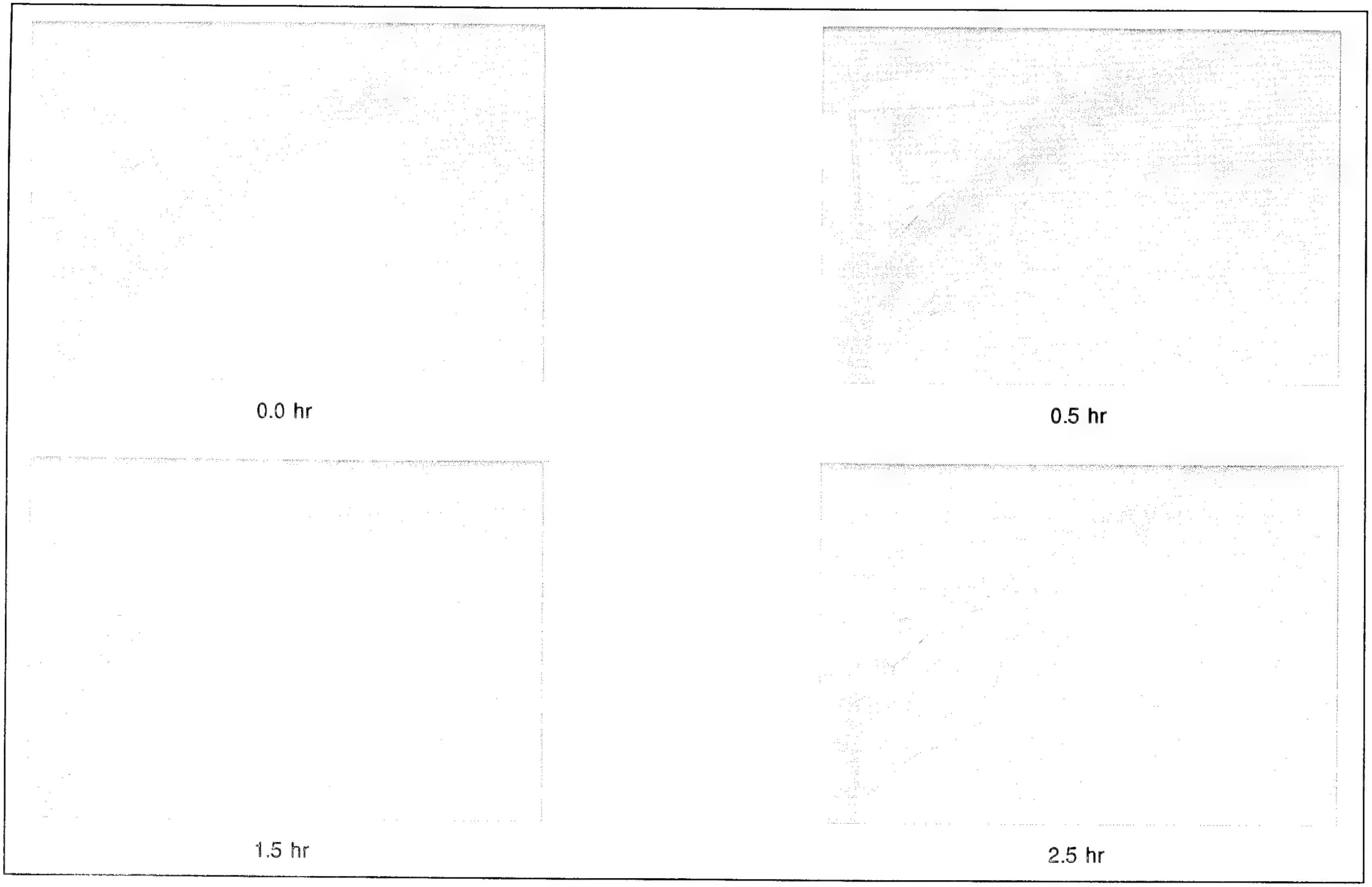
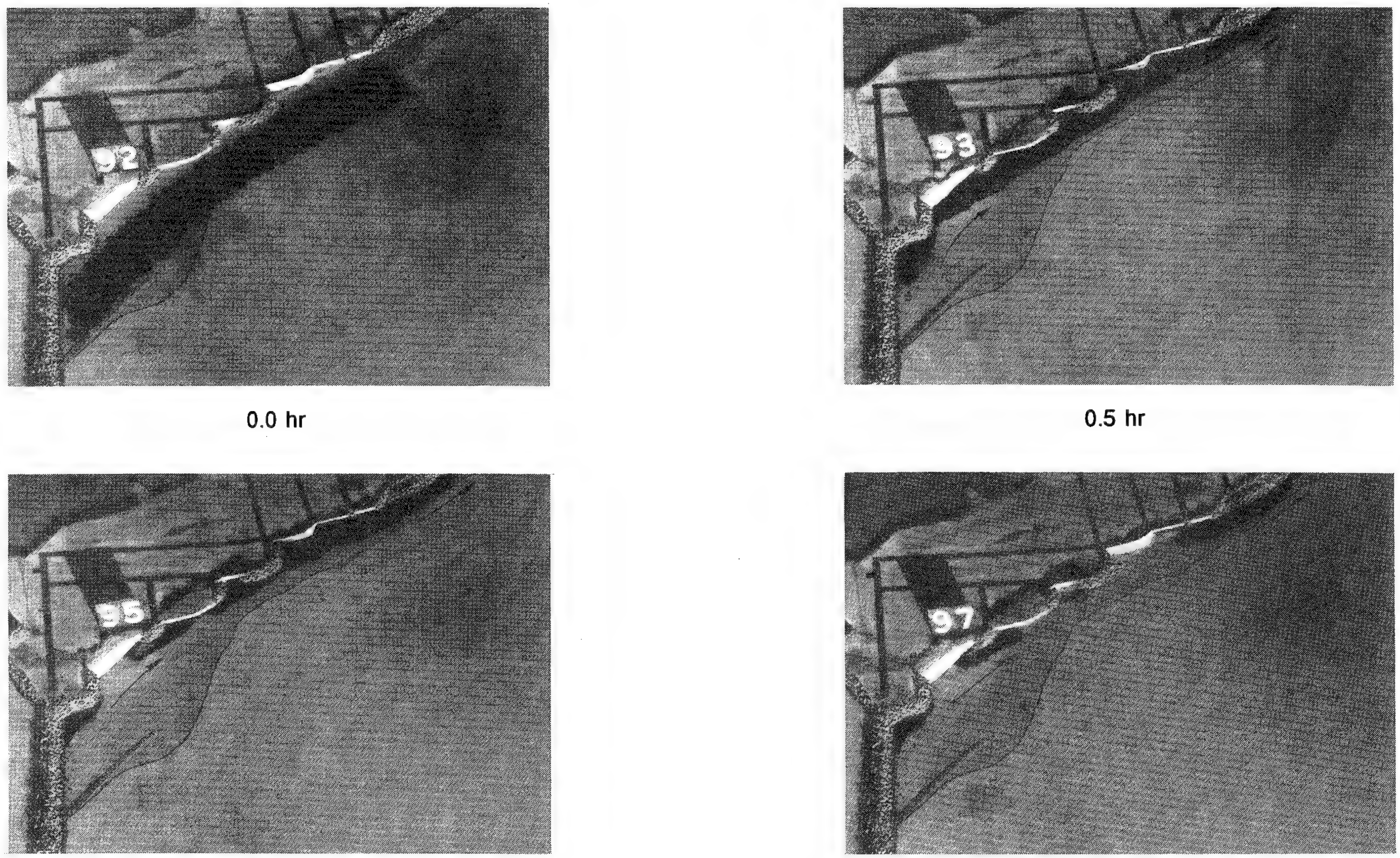


Photo 60. Progression of sediment tracer movement for Plan 1; 11-sec, 14-ft test waves from 88 deg; swl = +8.8 ft



0.0 hr

0.5 hr

1.5 hr

2.5 hr

Photo 61. Progression of sediment tracer movement for Plan 1; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft

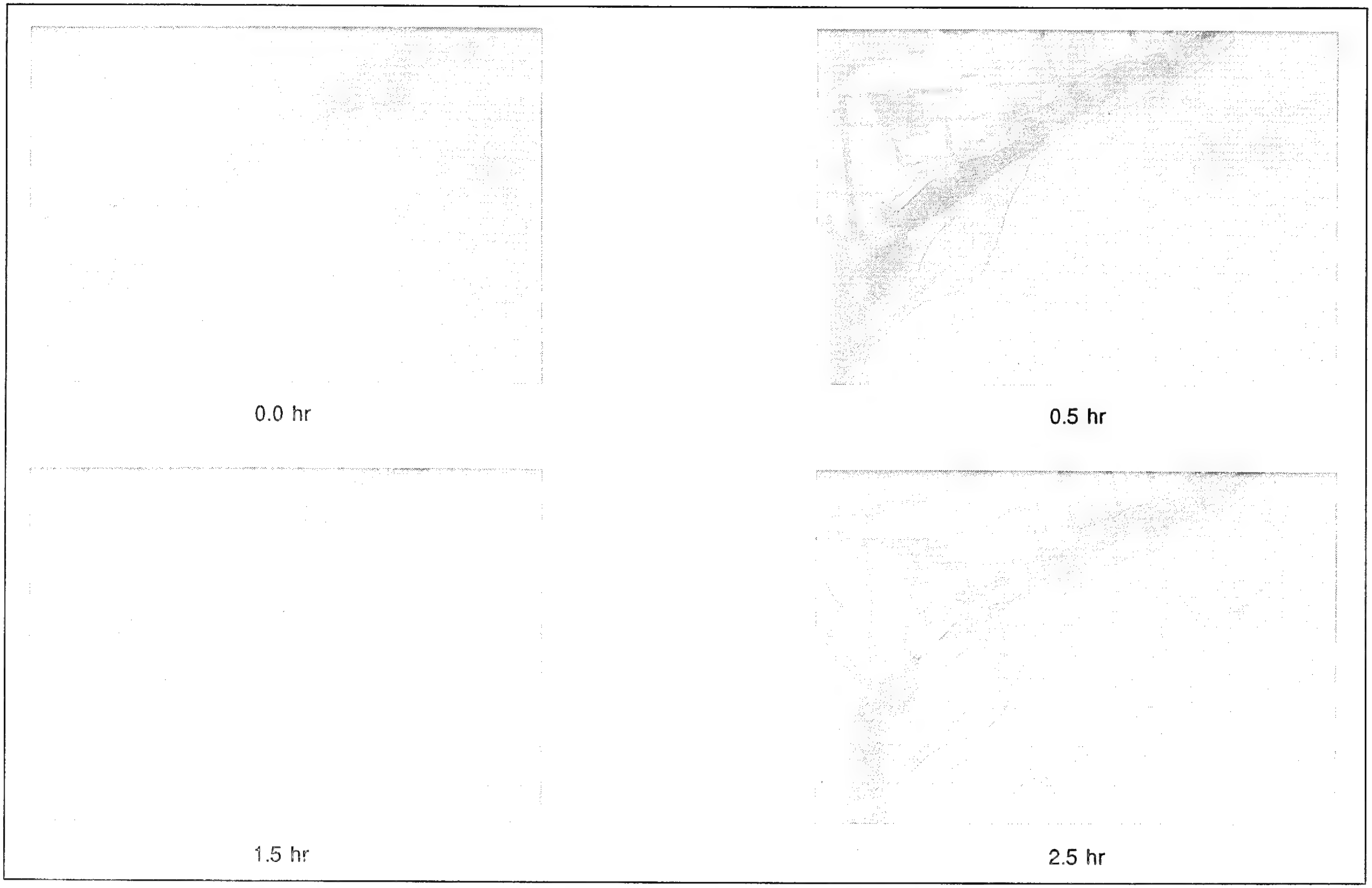


Photo 62. Progression of sediment tracer movement for Plan 1; 15-sec, 16-ft test waves from 88 deg; swl = +8.8 ft

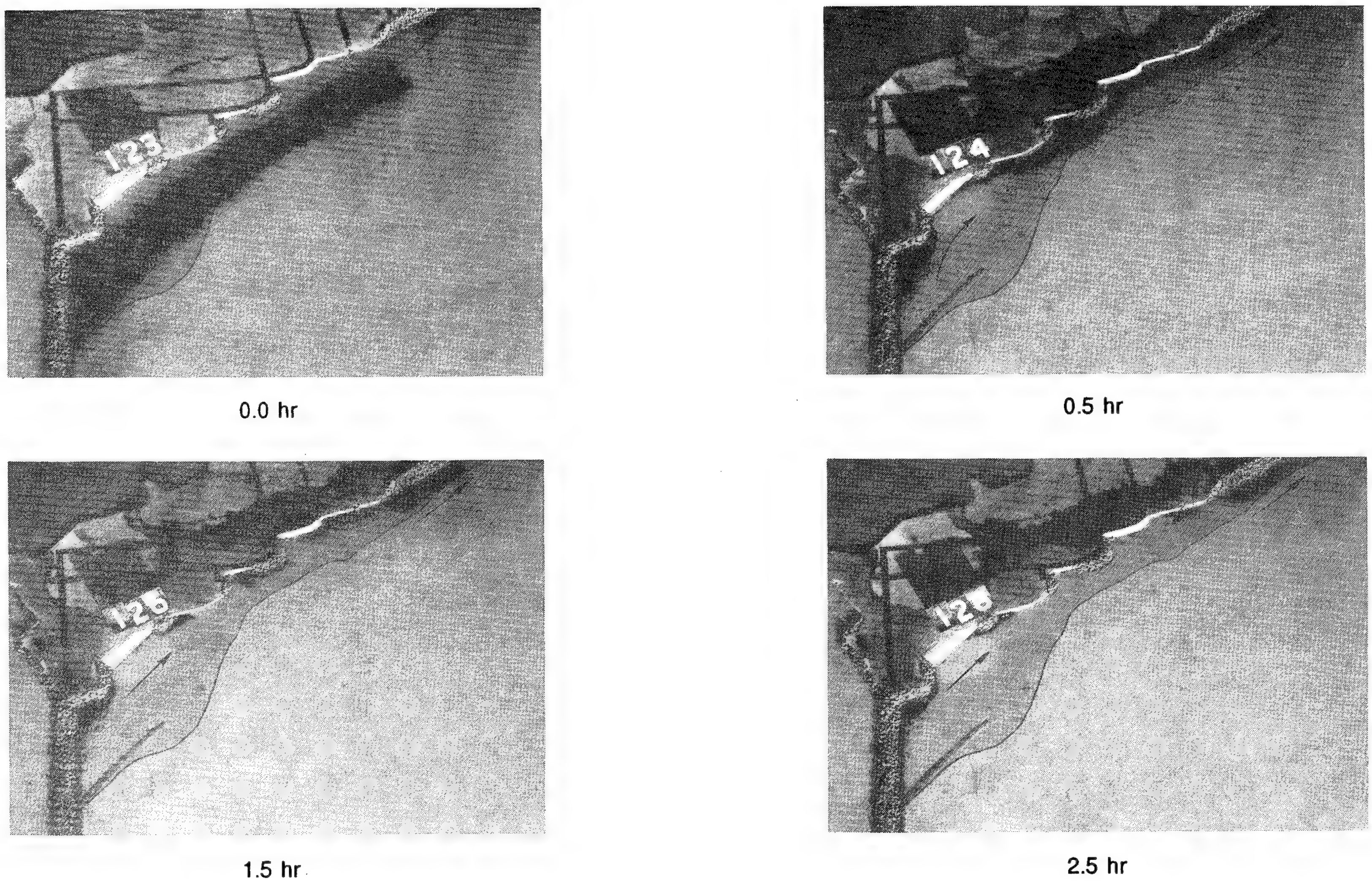


Photo 63. Progression of sediment tracer movement for Plan 1; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

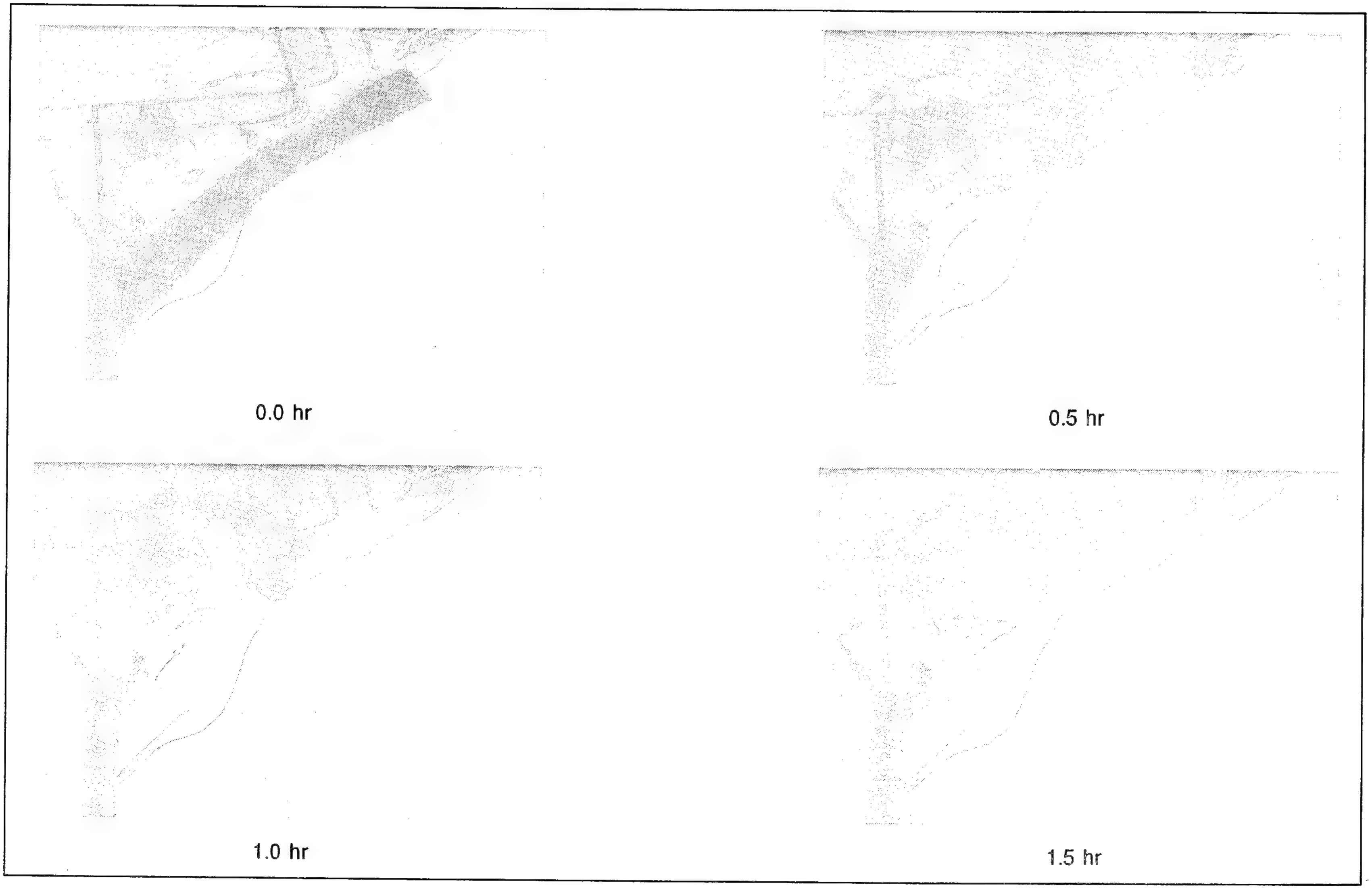
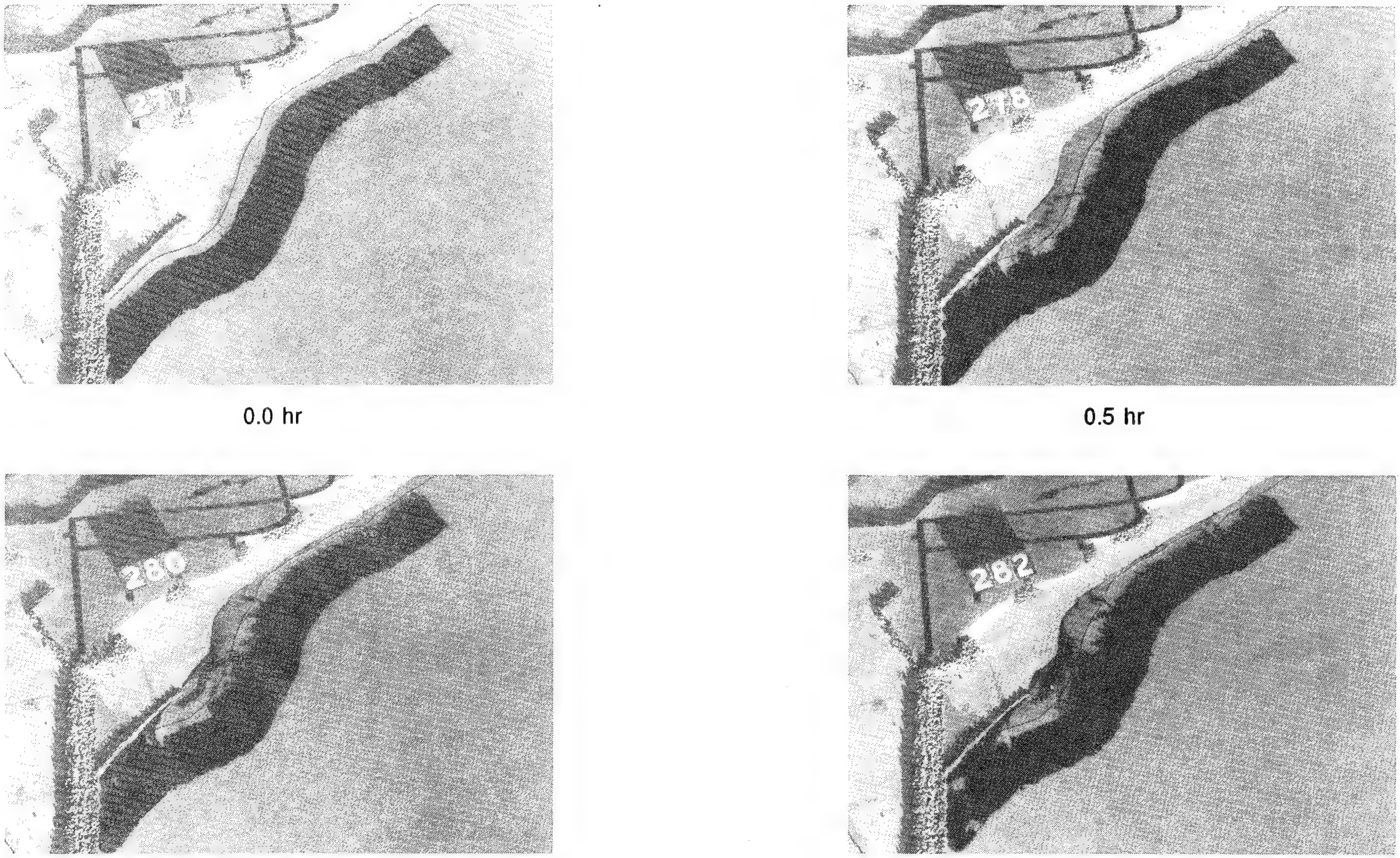


Photo 64. Progression of sediment tracer movement for Plan 1; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft



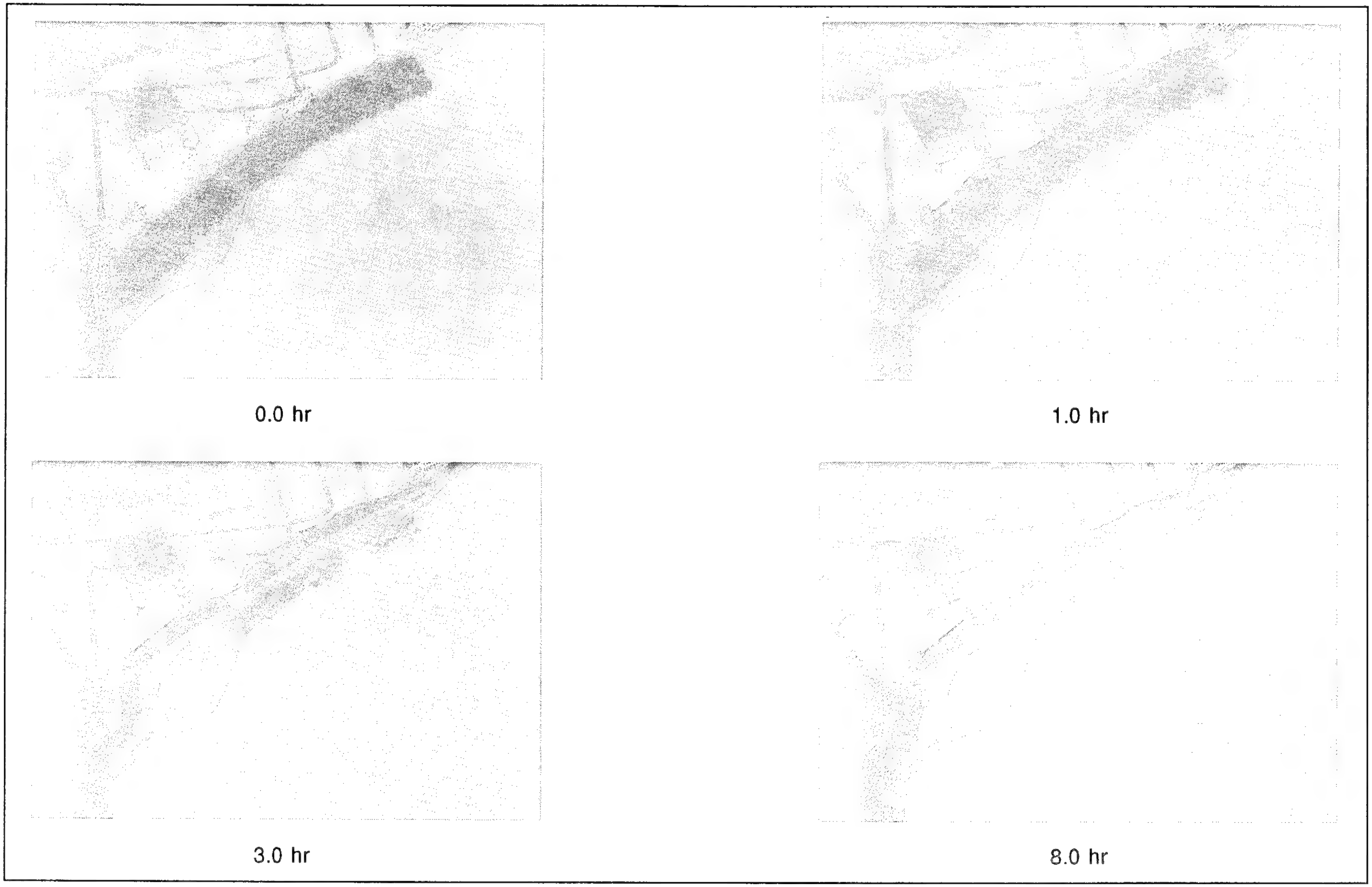
0.0 hr

0.5 hr

1.5 hr

2.5 hr

Photo 65. Progression of sediment tracer movement for Plan 1; 11-sec, 14-ft test waves from 75 deg; swl = 0.0 ft



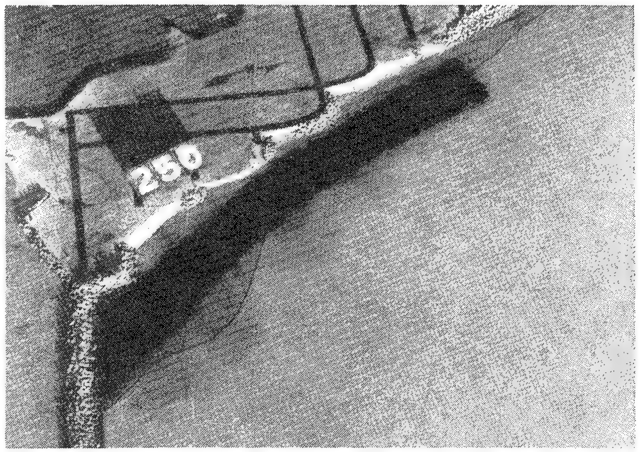
0.0 hr

1.0 hr

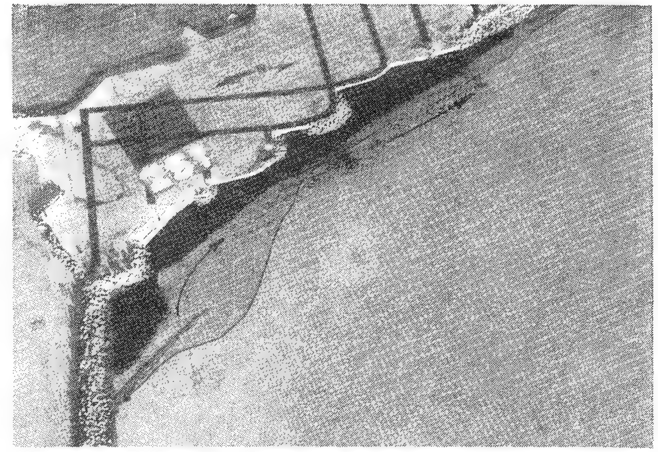
3.0 hr

8.0 hr

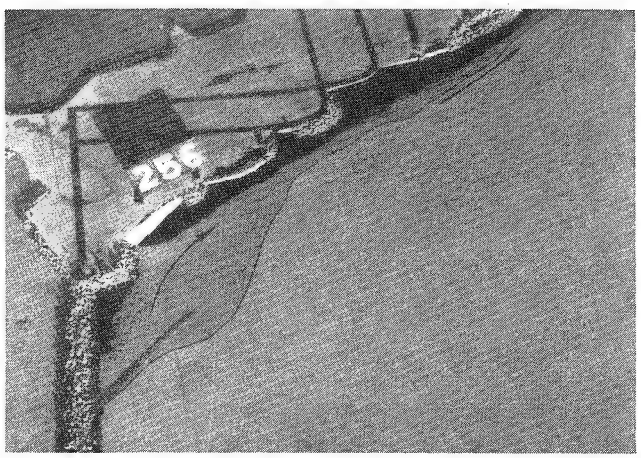
Photo 66. Progression of sediment tracer movement for Plan 1; 9-sec, 8-ft test waves from 75 deg; swl = +8.8 ft



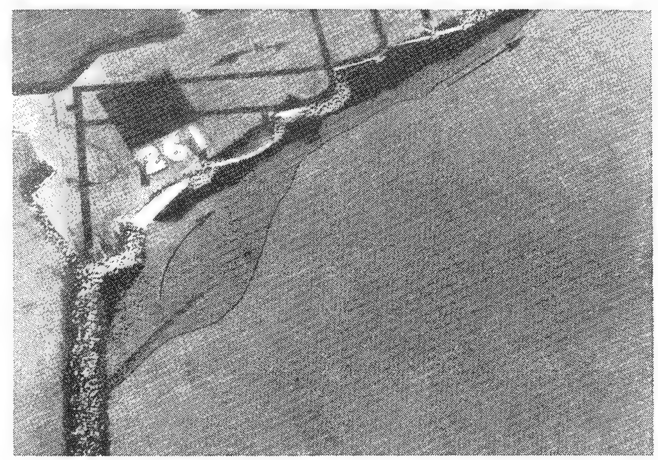
0.0 hr



1.0 hr



3.0 hr



6.0 hr

Photo 67. Progression of sediment tracer movement for Plan 1; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft

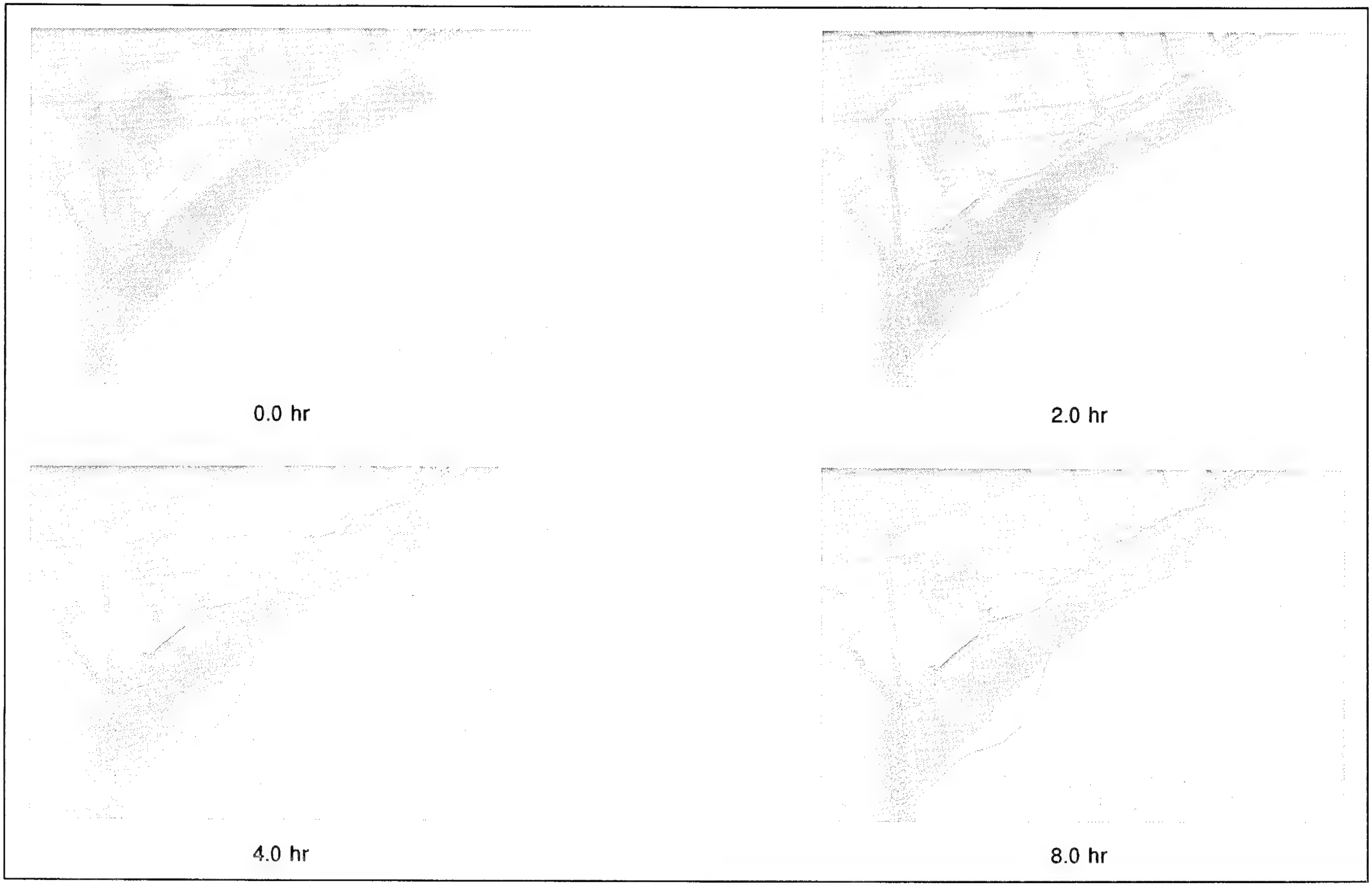
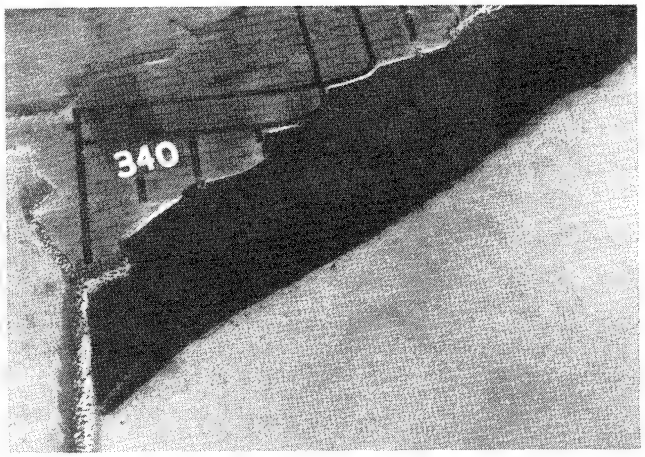
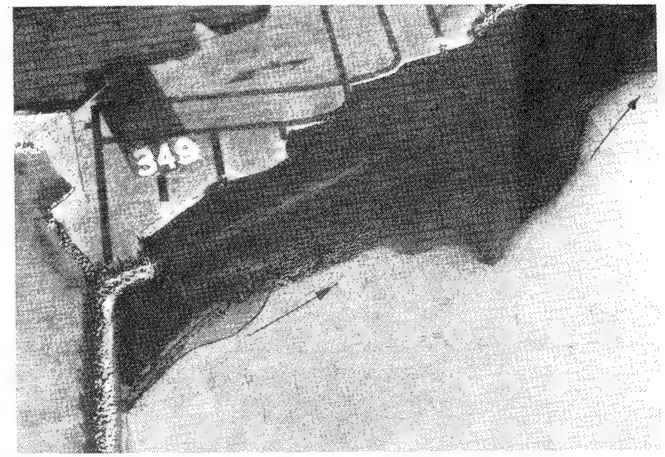


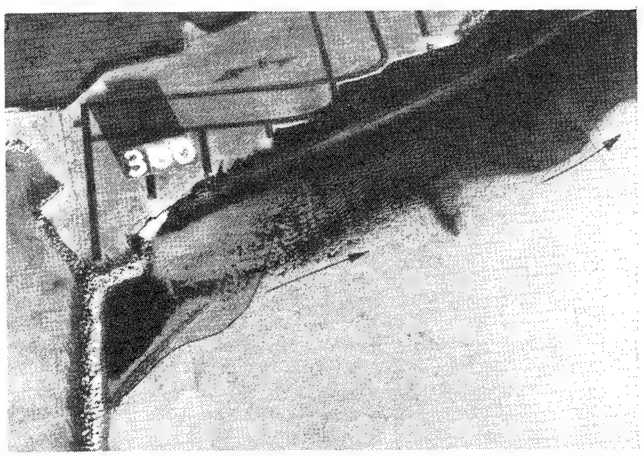
Photo 68. Progression of sediment tracer movement for Plan 1; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft



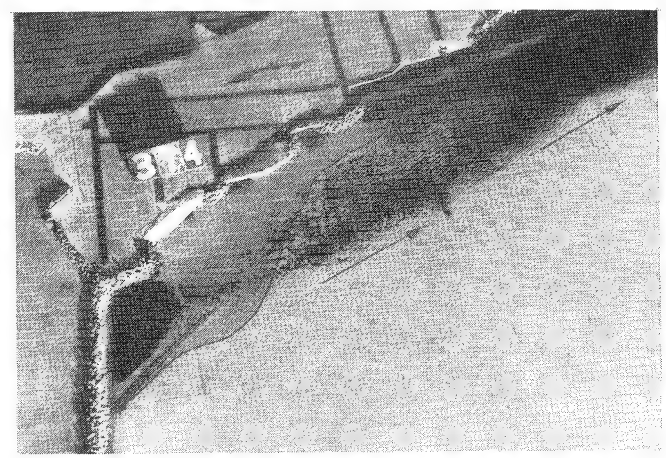
0.0 hr



5.0 hr

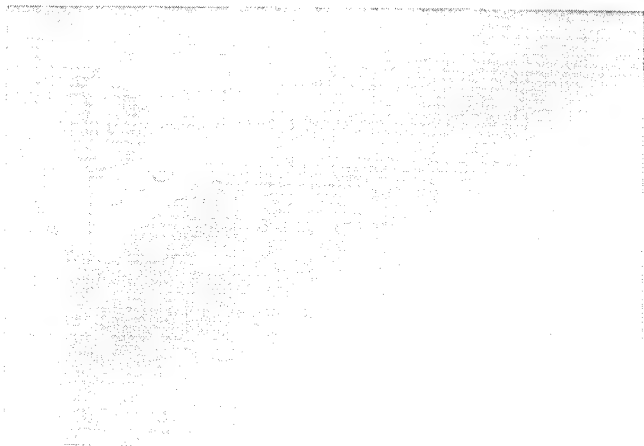


15.0 hr

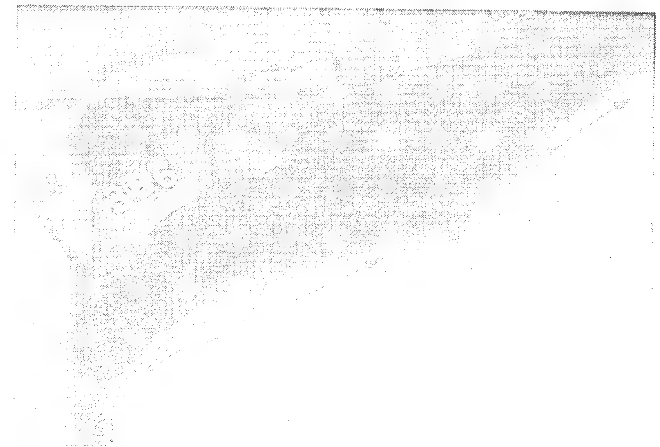


30.0 hr

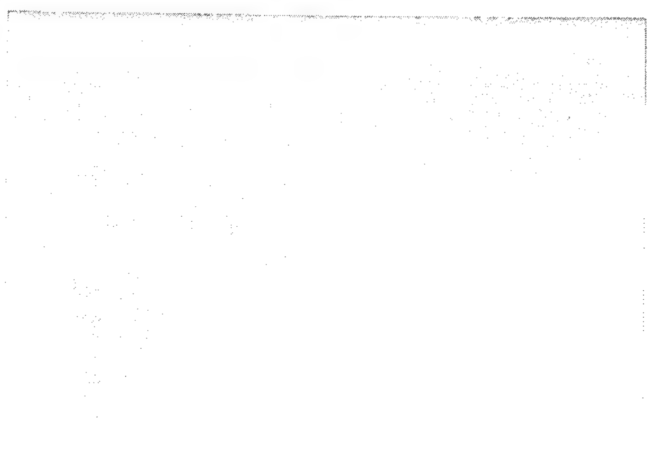
Photo 69. Progression of sediment tracer movement for Plan 2 beachfill; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft



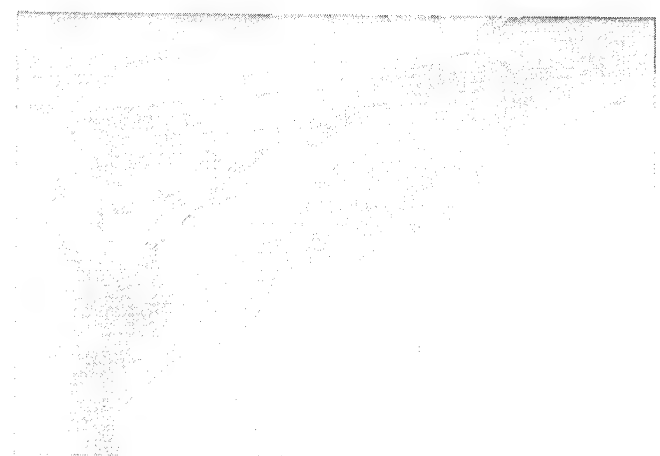
0.0 hr



5.0 hr



15.0 hr



30.0 hr

Photo 70. Progression of sediment tracer movement for Plan 3 beachfill; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

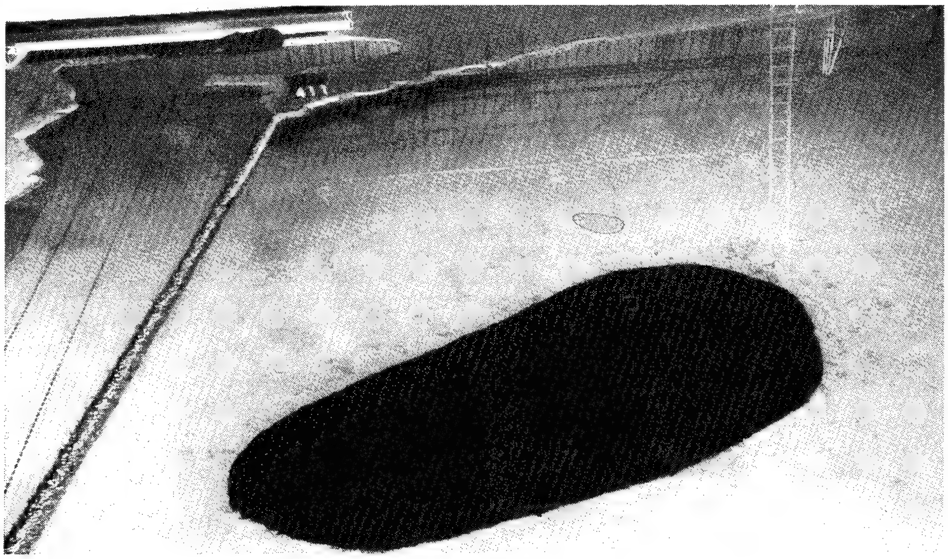


Photo 71. View of Plan 4 submerged berm prior to testing

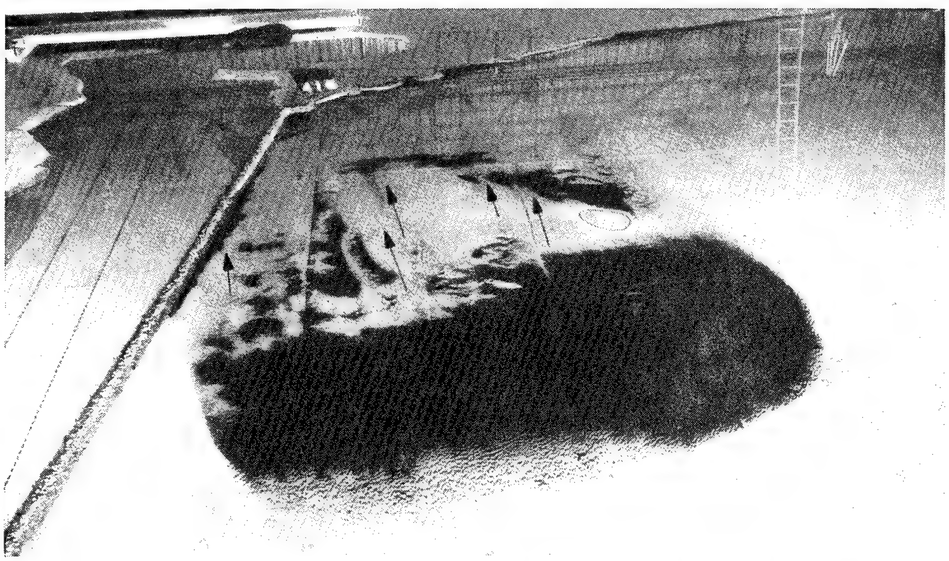


Photo 72. Movement of Plan 4 submerged offshore berm after 2.5 hr of testing; swl = +8.8 ft

Photo 73. Movement of Plan 4 submerged offshore berm after 5 hr of testing; swl = +8.8 ft

Photo 74. Movement of Plan 4 submerged offshore berm after 8 hr of testing; swl = +8.8 ft

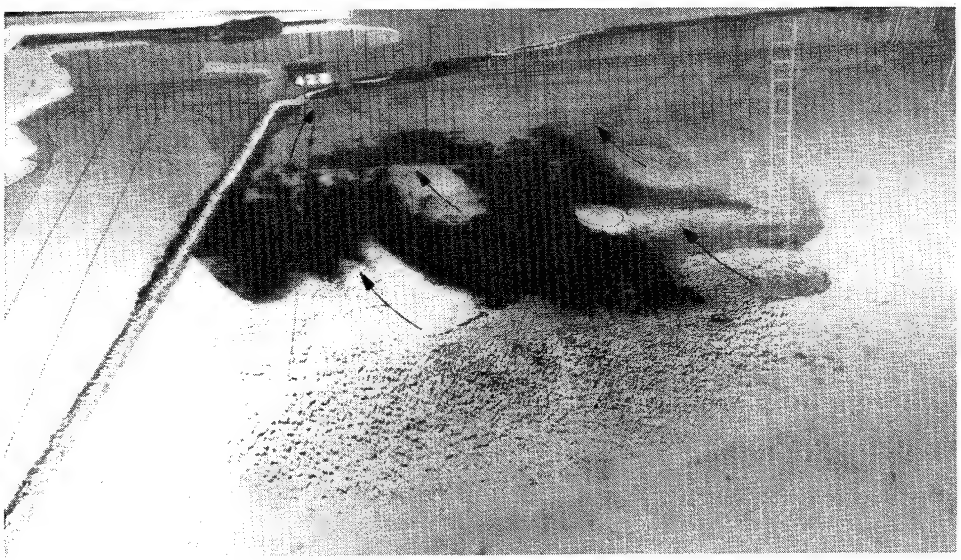


Photo 75. Movement of Plan 4 submerged offshore berm after 11 hr of testing; swl = +8.8 ft

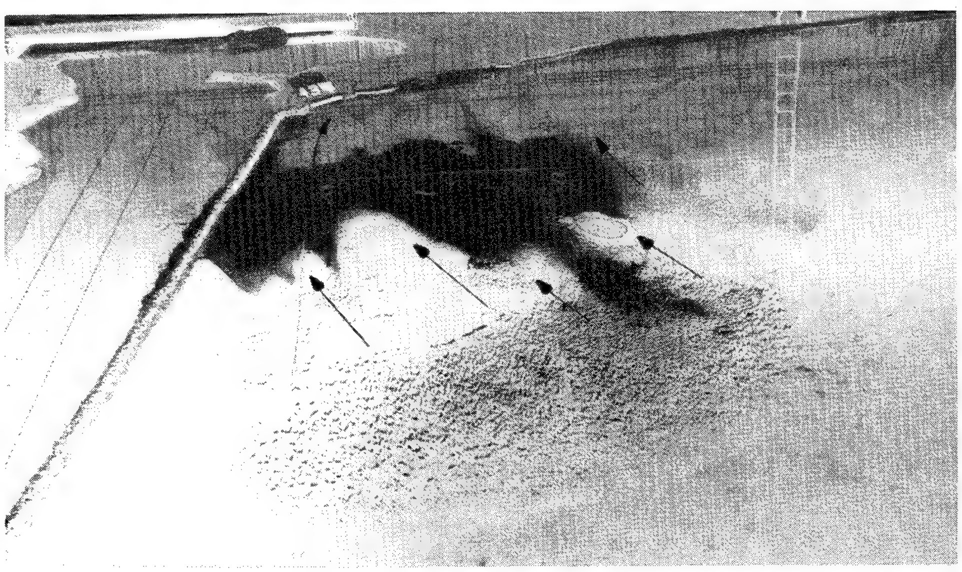


Photo 76. Movement of Plan 4 submerged offshore berm after 15 hr of testing; swl = +8.8 ft

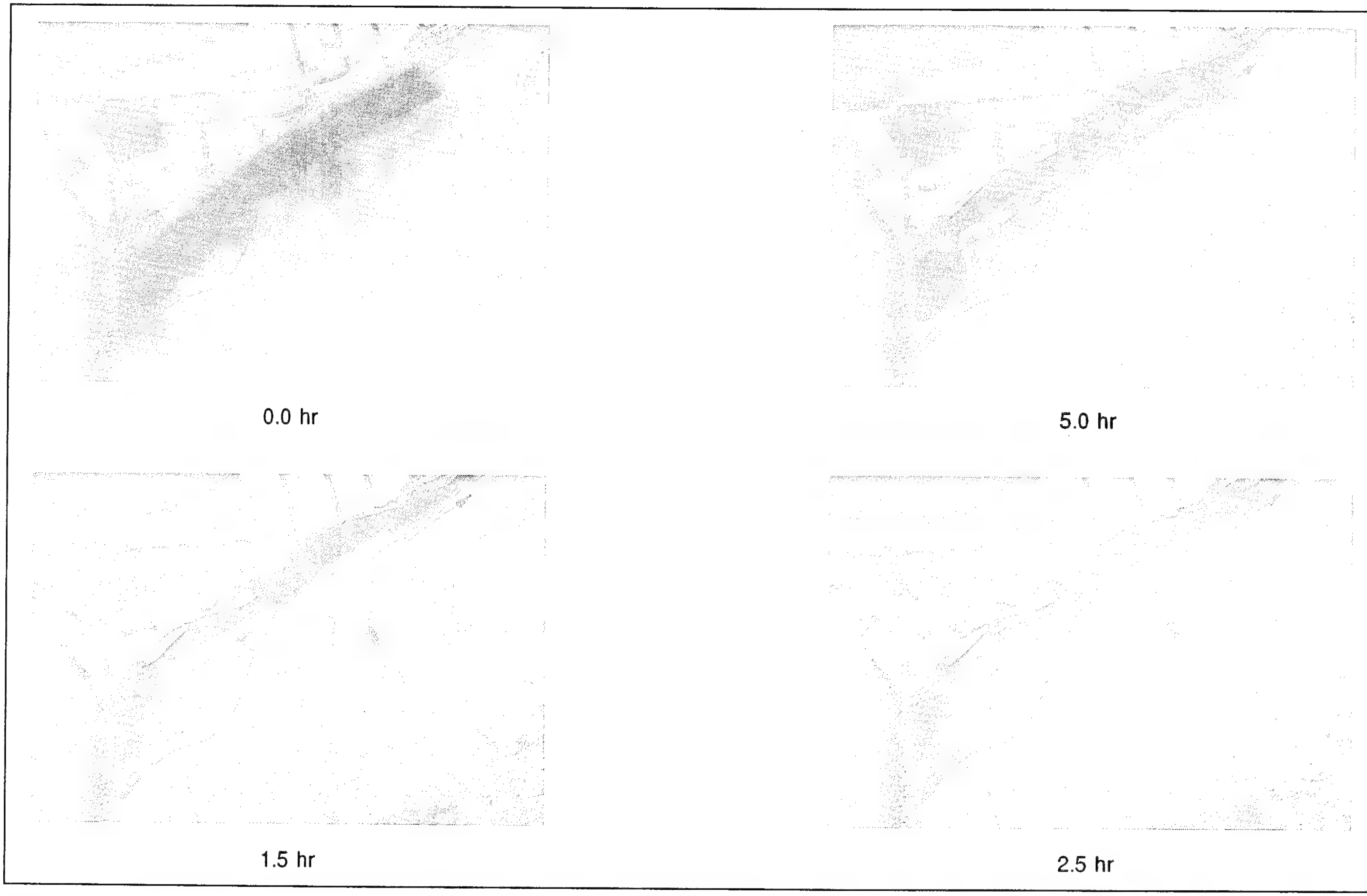


Photo 77. Progression of sediment tracer movement along shoreline for Plan 4; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

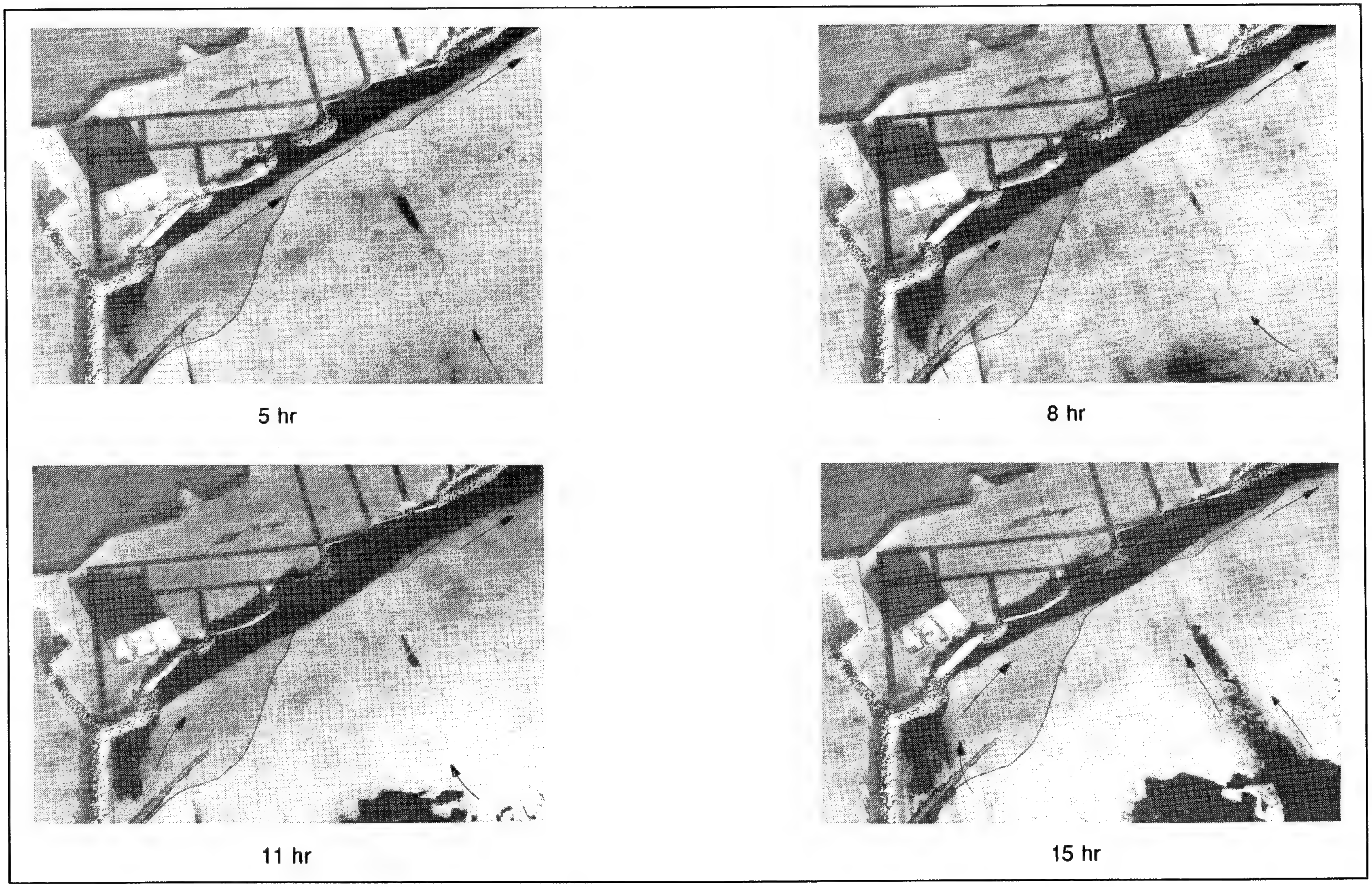


Photo 78. Progression of sediment tracer movement along shoreline for Plan 4 from 5 to 15 hr of testing; swl = +8.8 ft

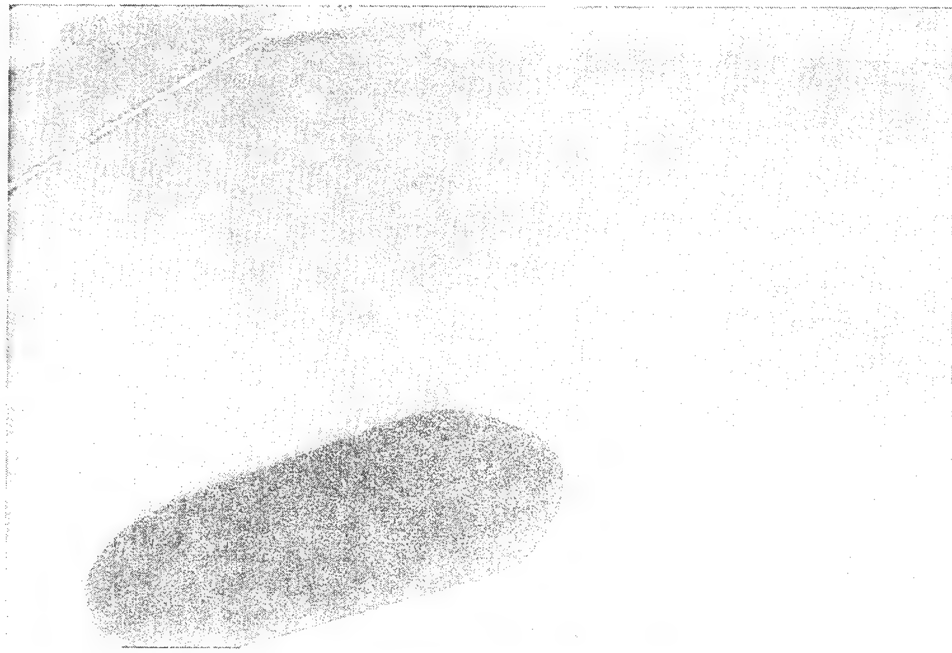


Photo 79. View of Plan 5 submerged berm prior to testing

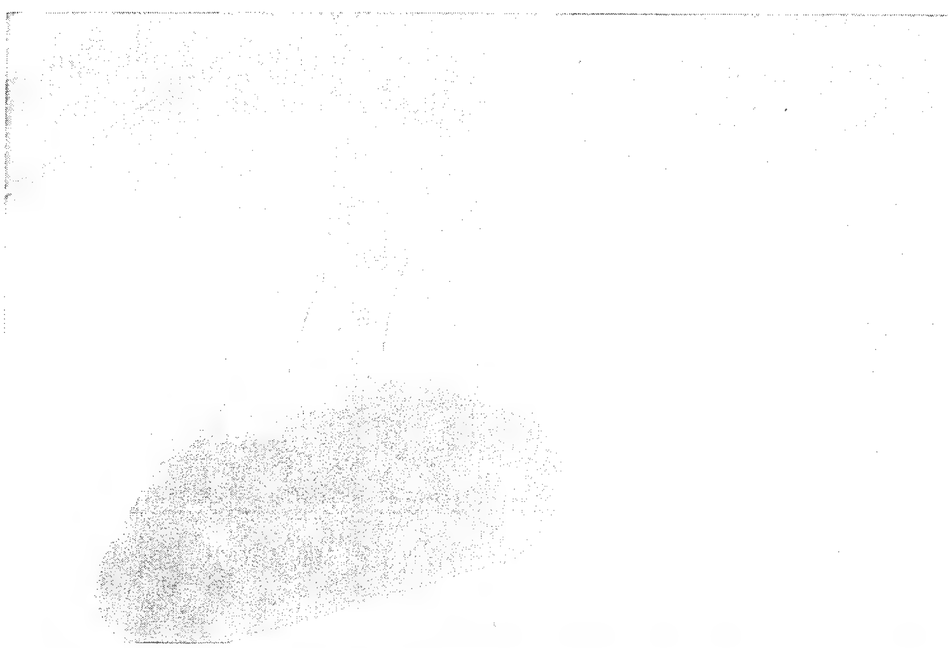


Photo 80. Movement of Plan 5 submerged offshore berm after 2.5 hr of testing; swl = +8.8 ft

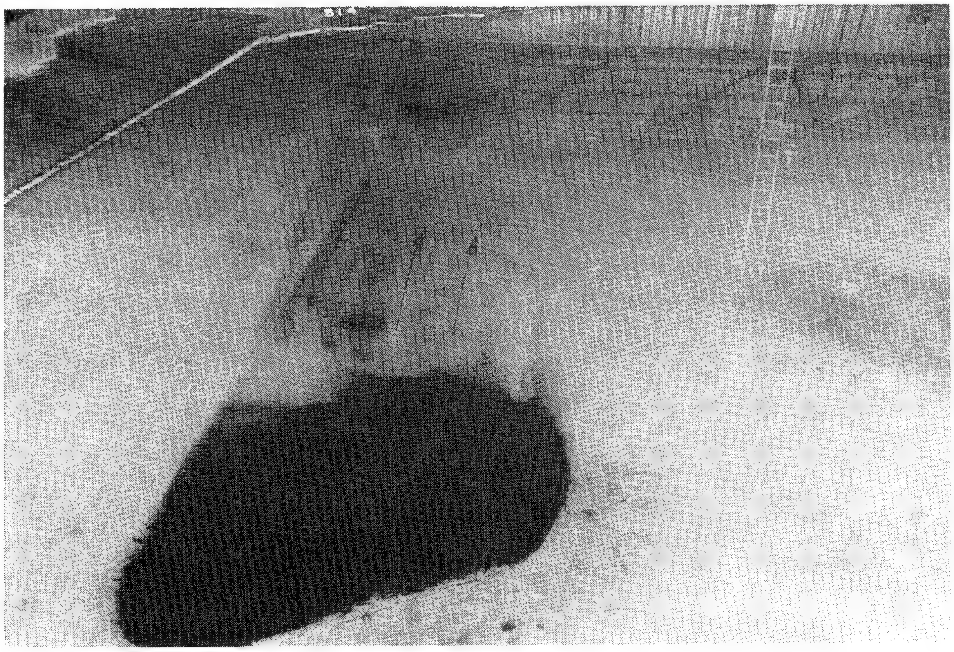


Photo 81. Movement of Plan 5 submerged offshore berm after 5 hr of testing; swl = +8.8 ft

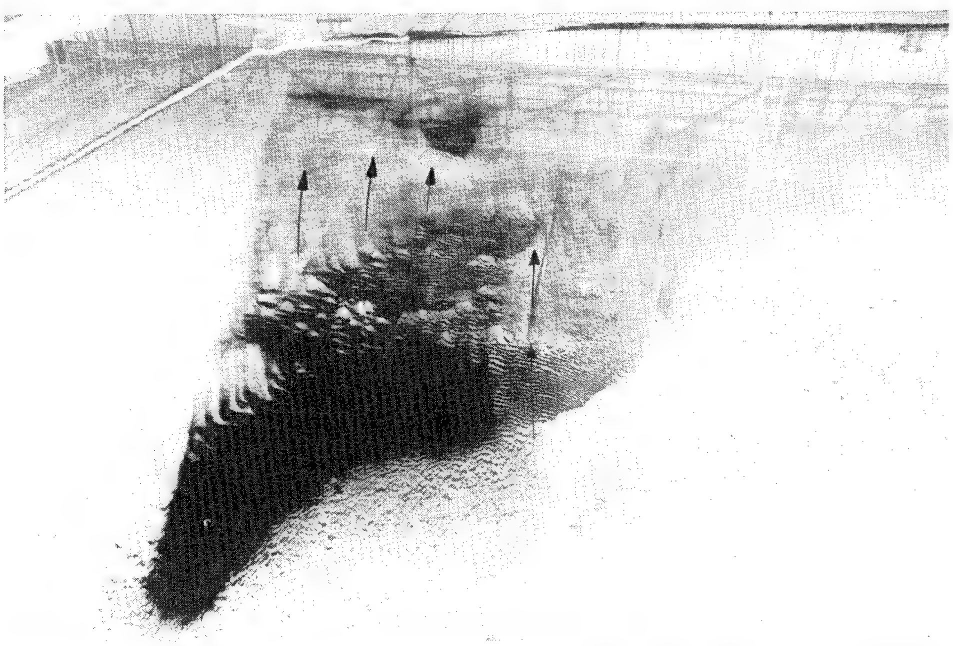


Photo 82. Movement of Plan 5 submerged offshore berm after 8 hr of testing; swl = +8.8 ft

Photo 83. Movement of Plan 5 submerged offshore berm after 11 hr of testing; swl = +8.8 ft

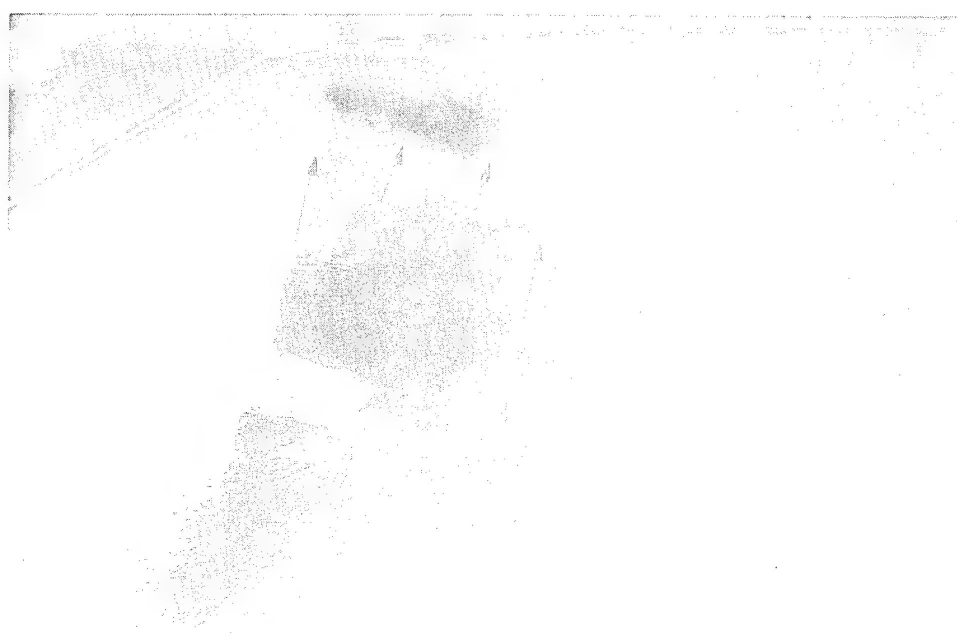
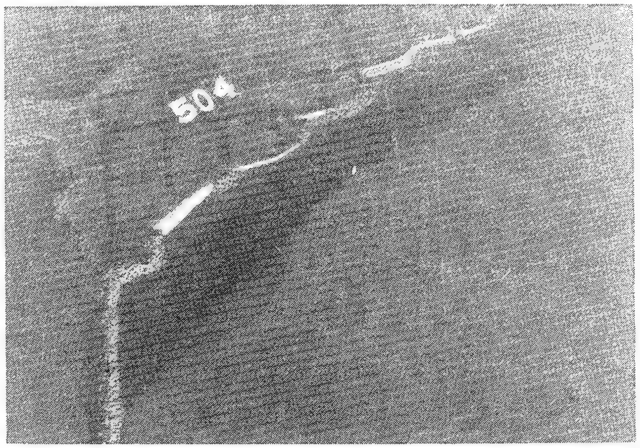
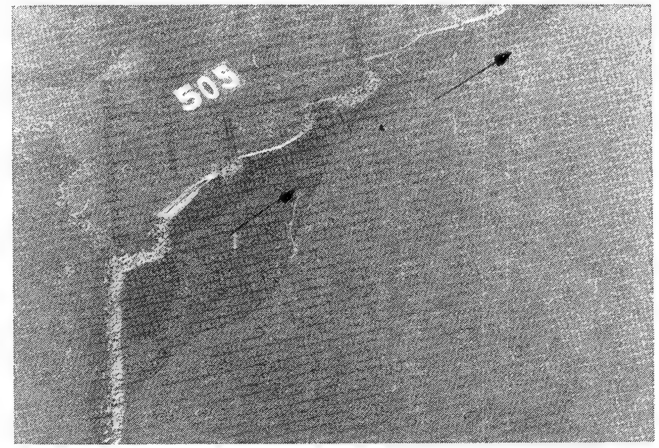


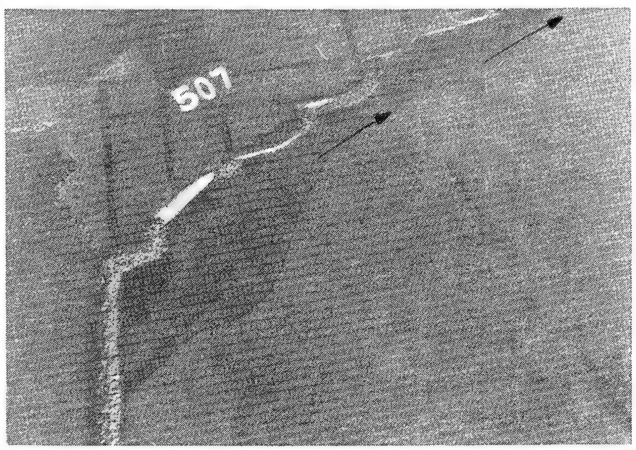
Photo 84. Movement of Plan 5 submerged offshore berm after 15 hr of testing; swl = +8.8 ft



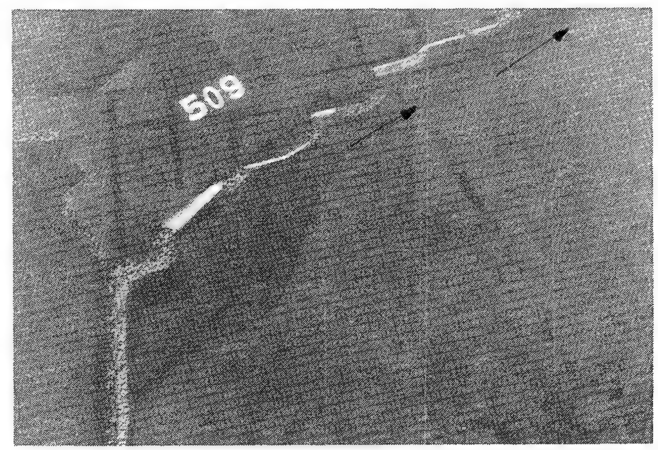
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 85. Progression of sediment tracer movement along shoreline for Plan 5; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

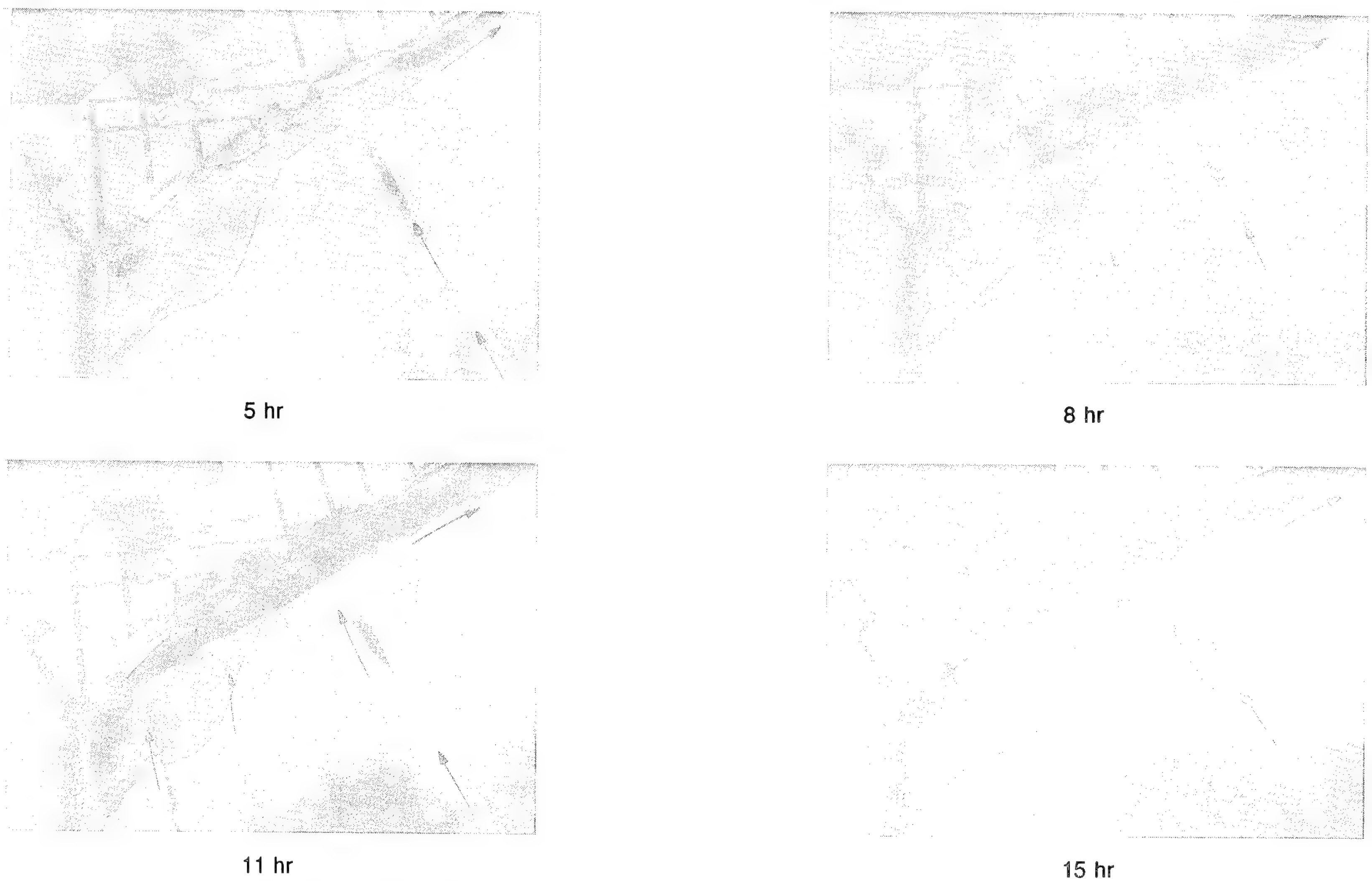


Photo 86. Progression of sediment tracer movement along shoreline for Plan 5 from 5 to 15 hr of testing; swl = +8.8 ft

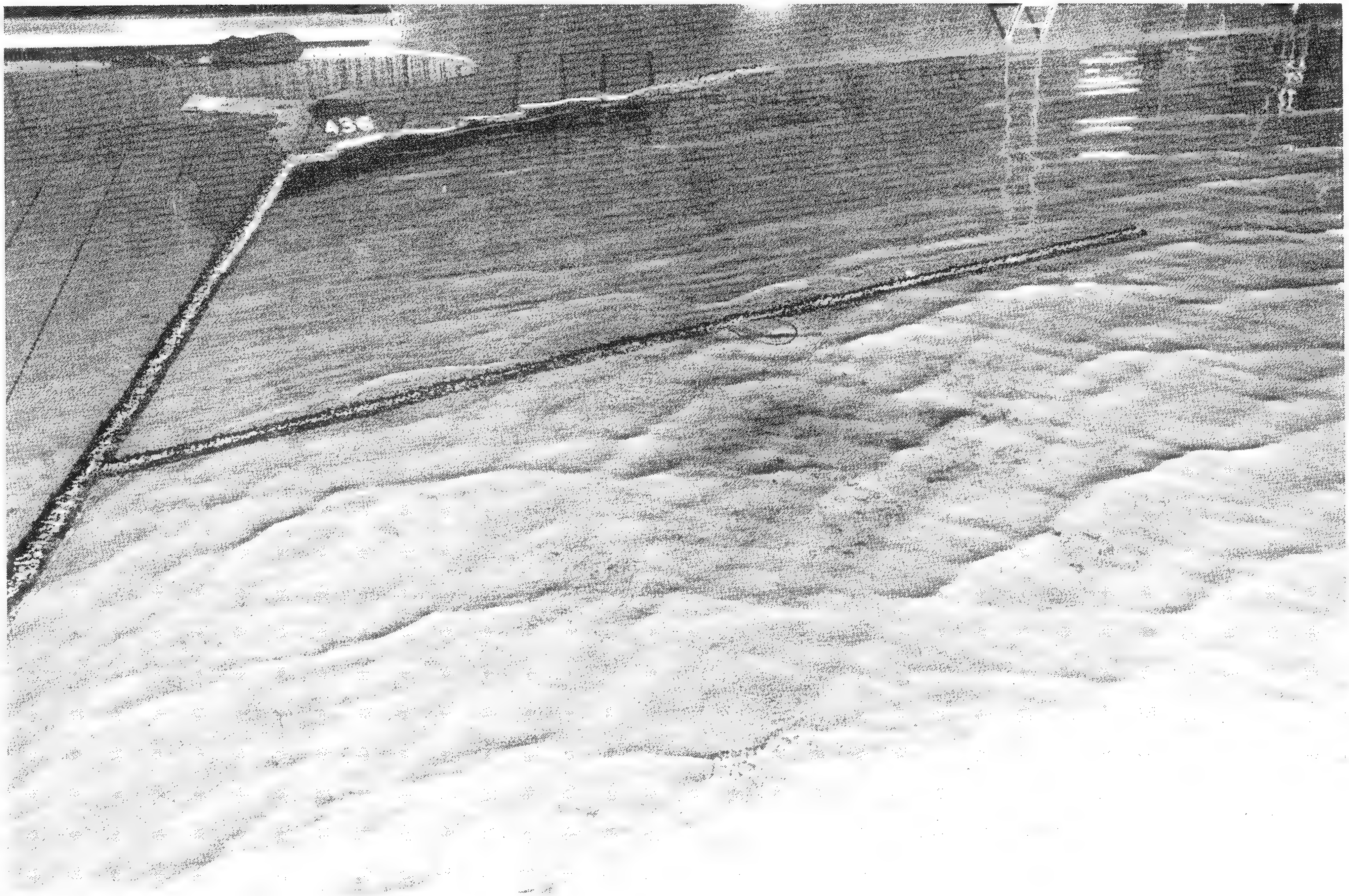
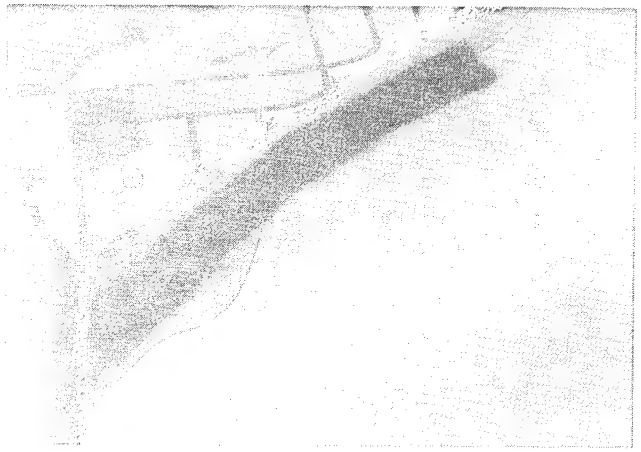
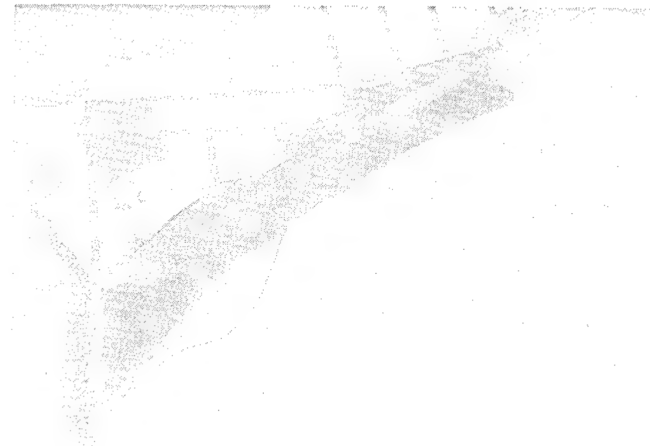


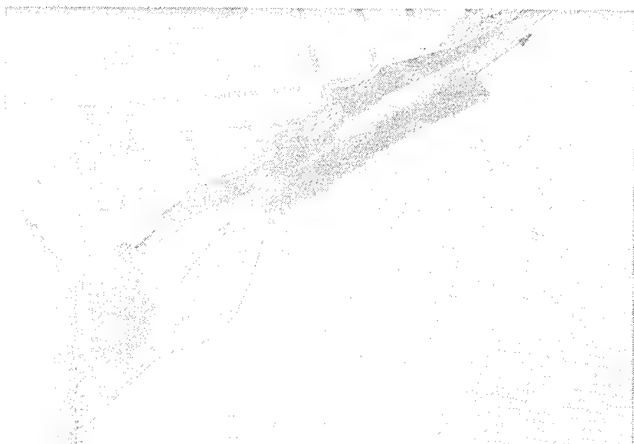
Photo 87. Typical wave patterns for Plan 6; 13-sec, 12-ft waves from 101 deg; swl = +8.8 ft



0.0 hr



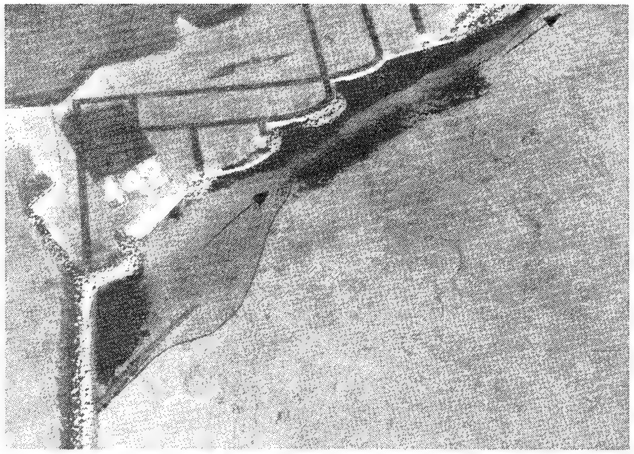
0.5 hr



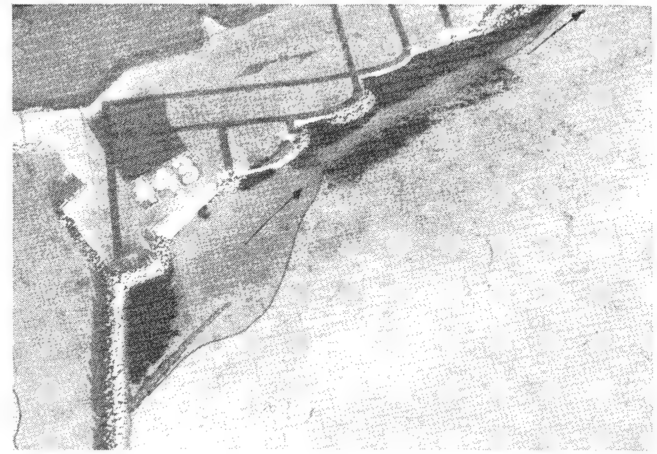
1.5 hr

2.5 hr

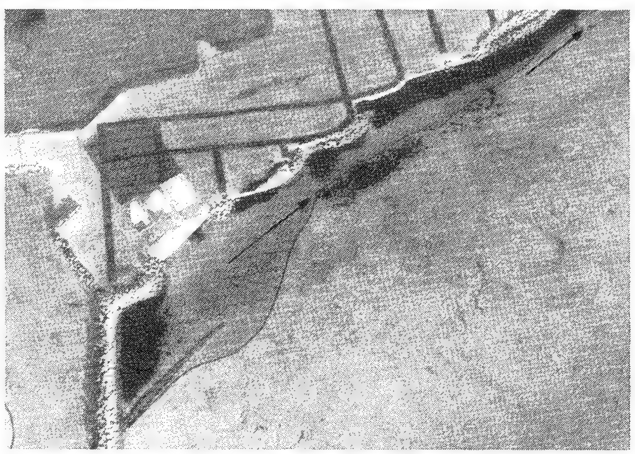
Photo 88. Progression of sediment tracer movement for Plan 6; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft (0-2.5 hr)



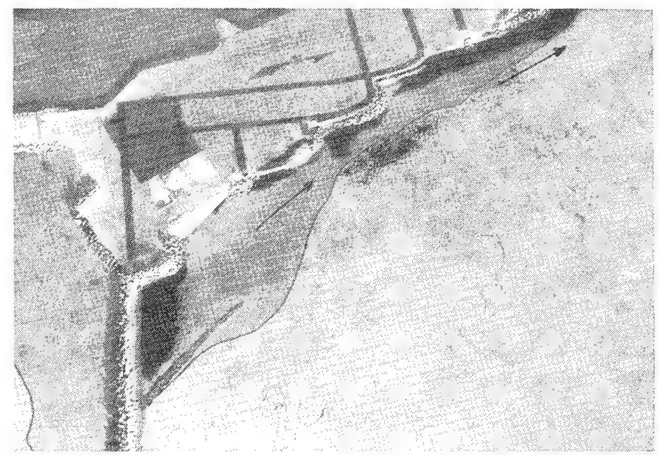
3.0 hr



4.0 hr



6.0 hr



8.0 hr

Photo 89. Progression of sediment tracer movement for Plan 6; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft (3-8 hr)

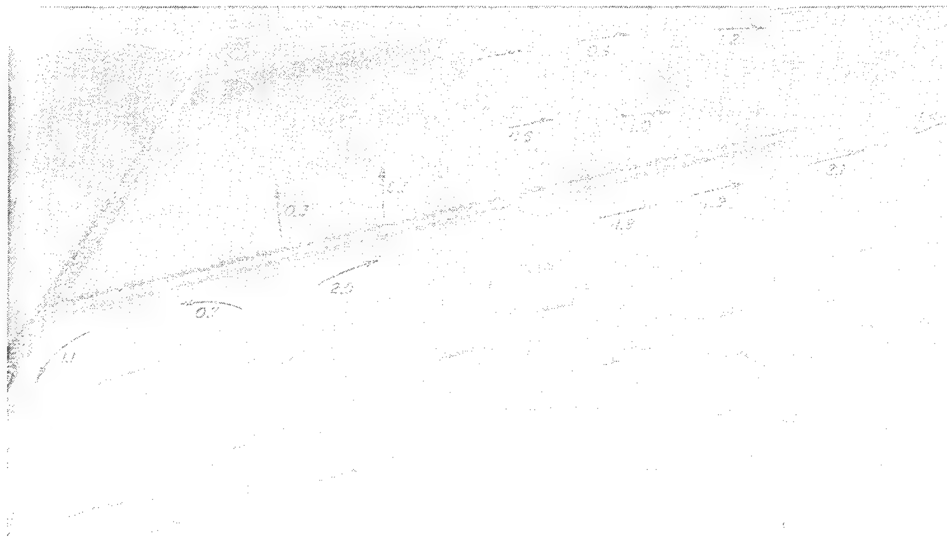


Photo 90. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 7; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

Photo 91. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 7; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft

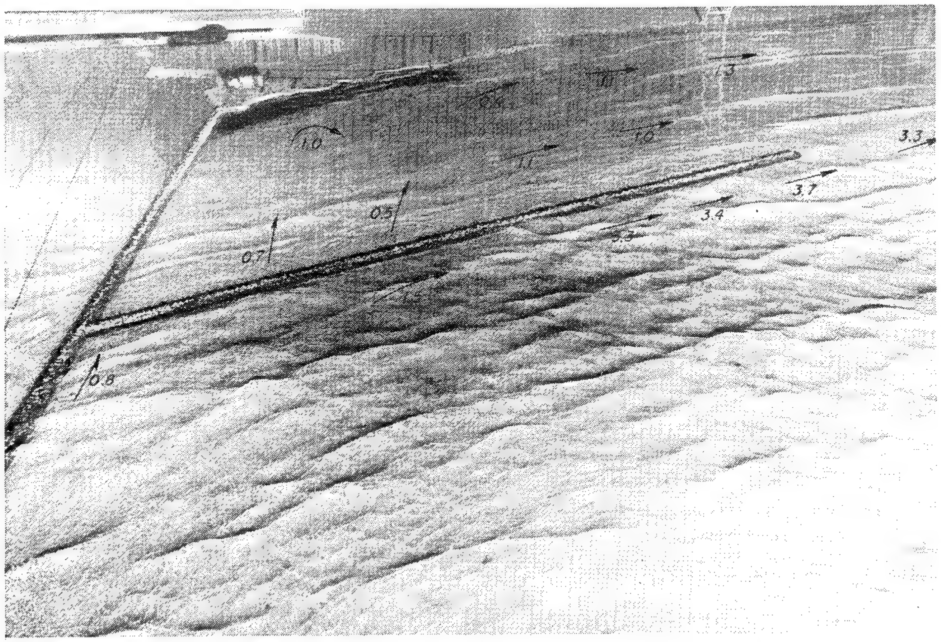


Photo 92. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 7; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

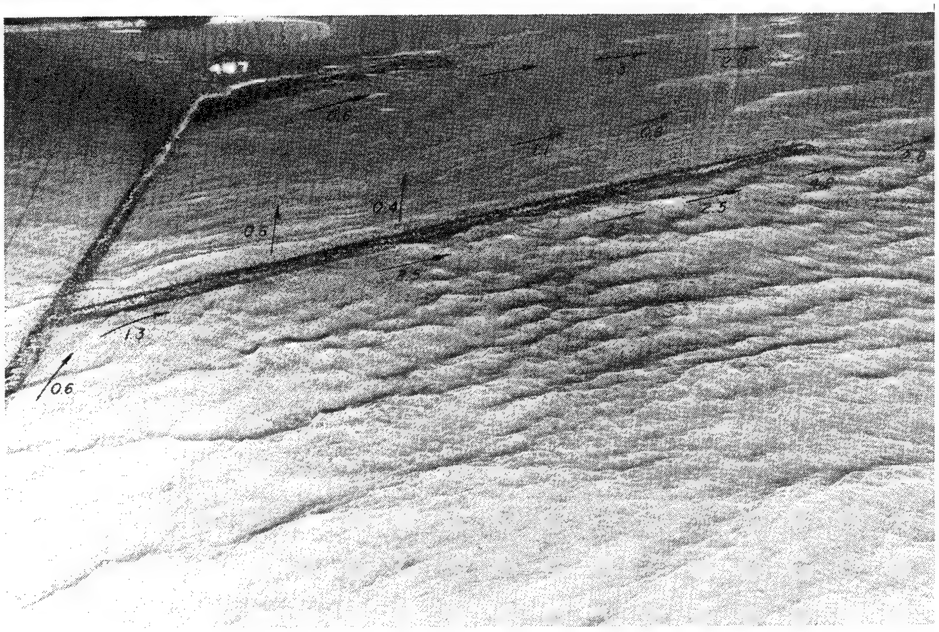


Photo 93. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 7; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

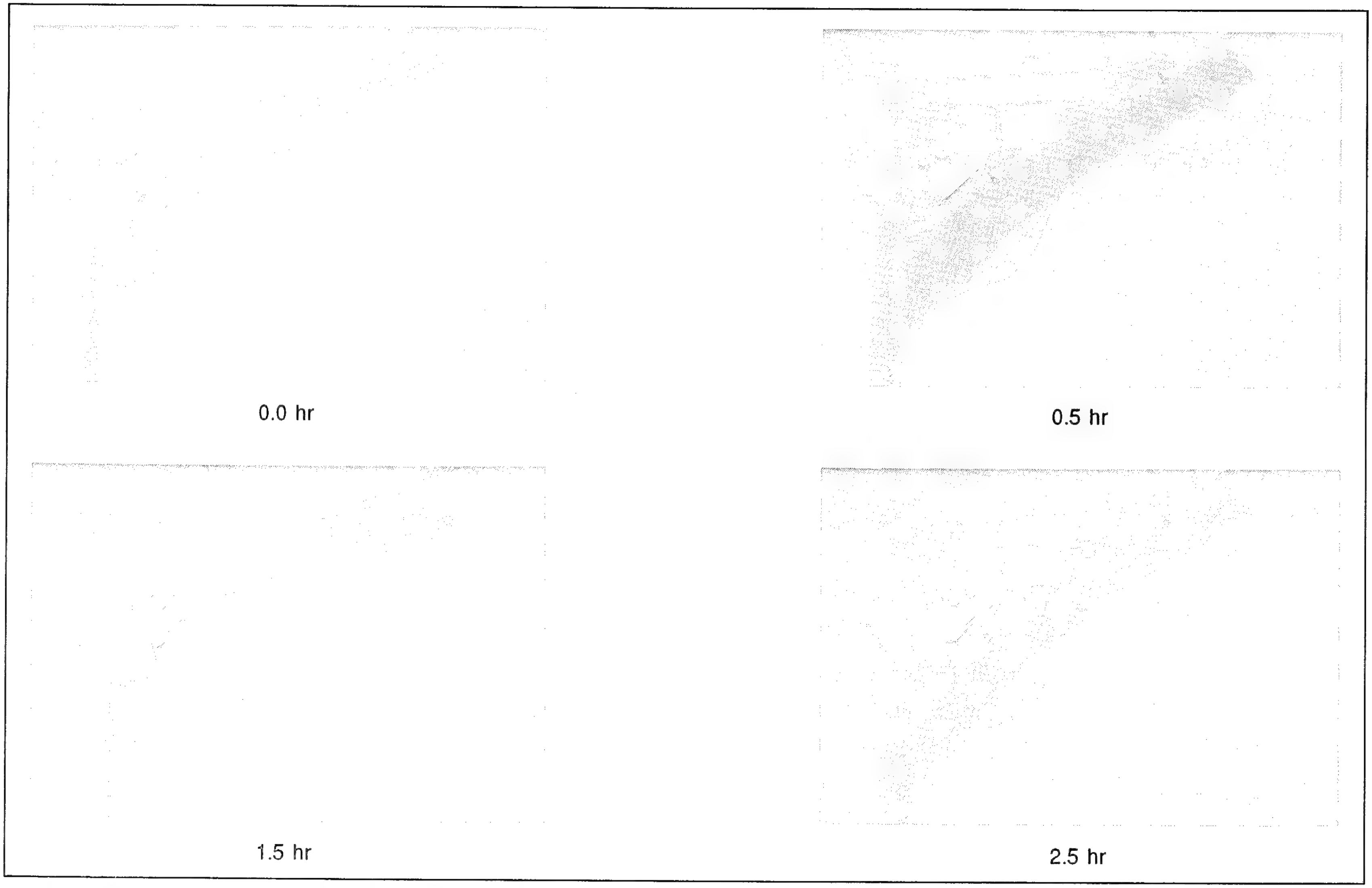
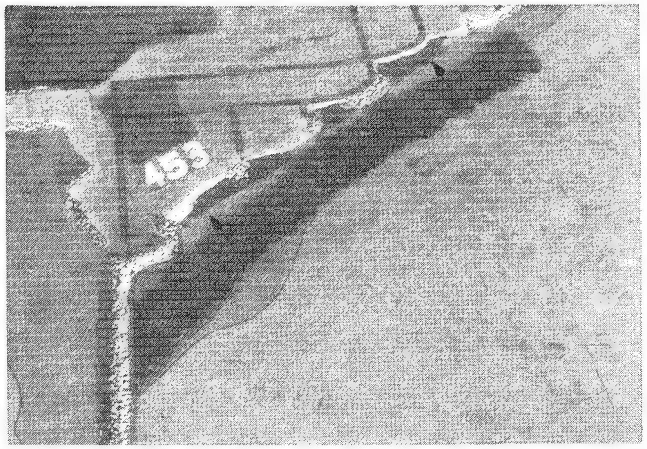
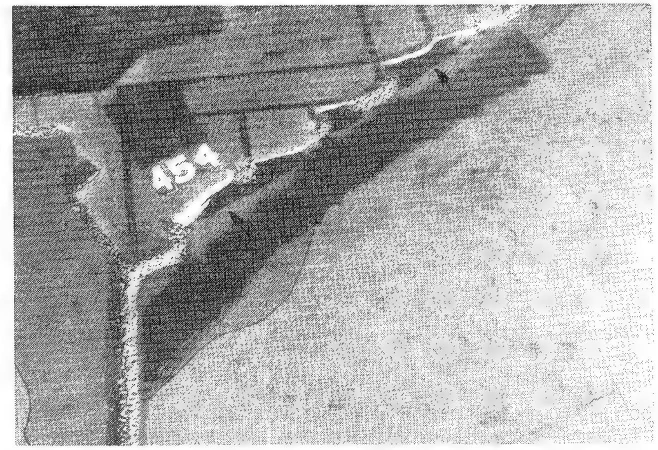


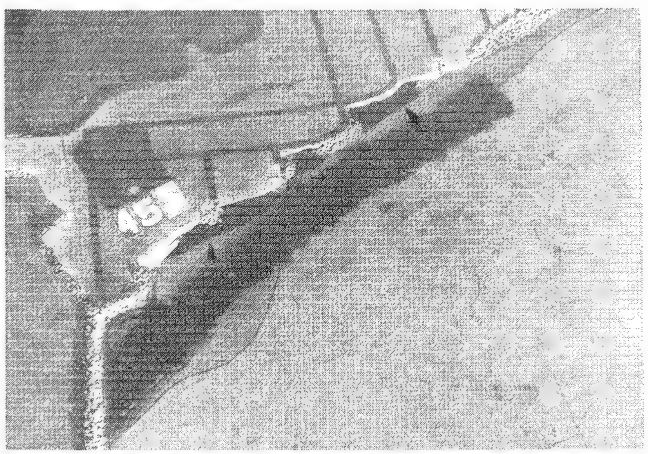
Photo 94. Progression of sediment tracer movement for Plan 7; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft (0-2.5 hr)



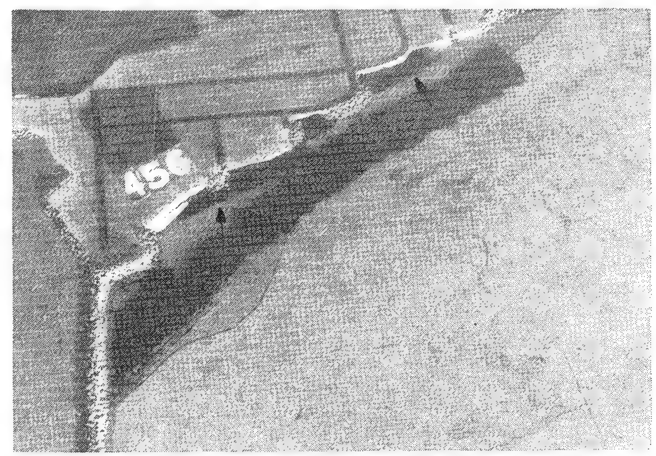
3.0 hr



4.0 hr



6.0 hr



8.0 hr

Photo 95. Progression of sediment tracer movement for Plan 7; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft (3-8 hr)

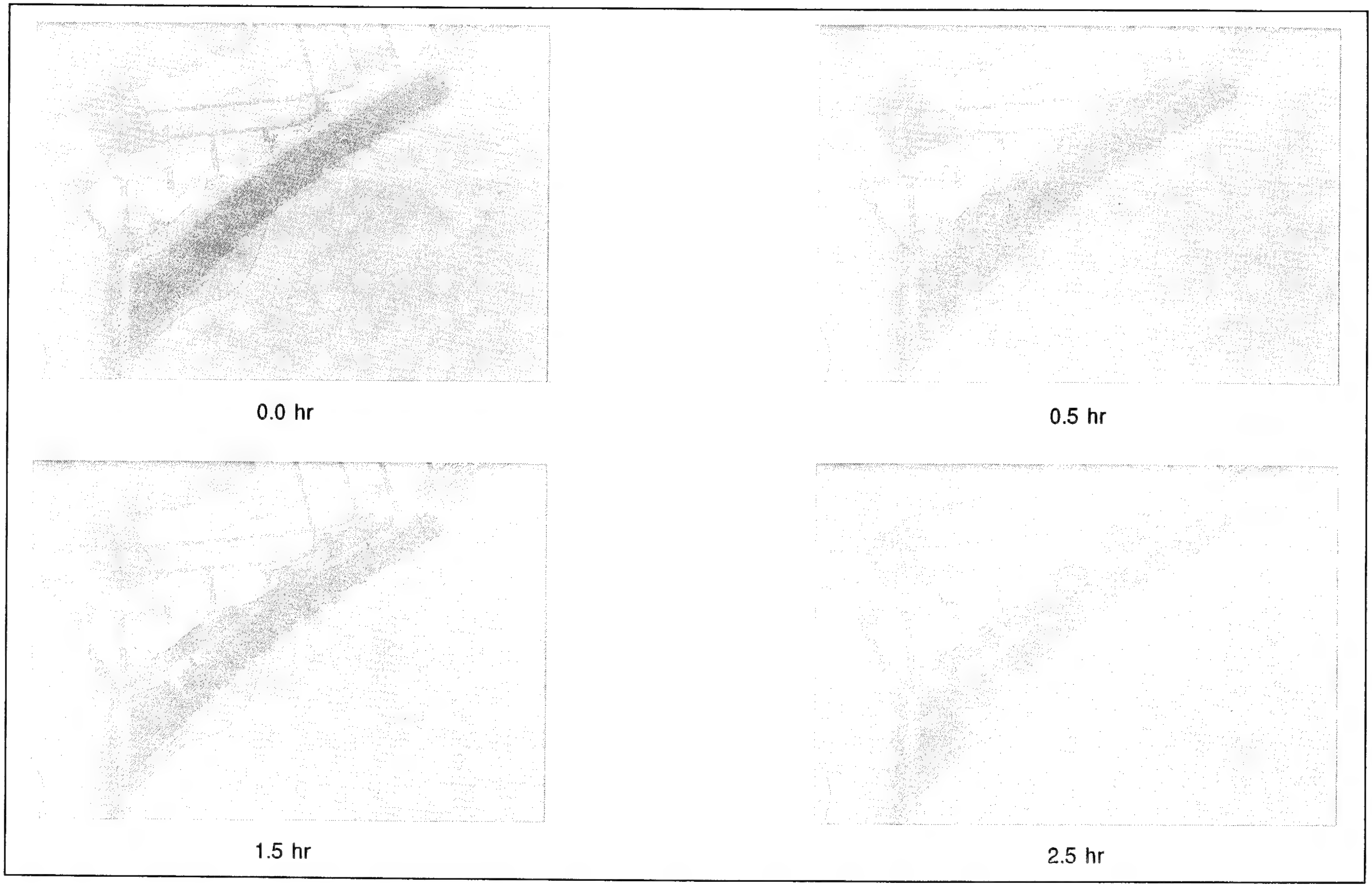
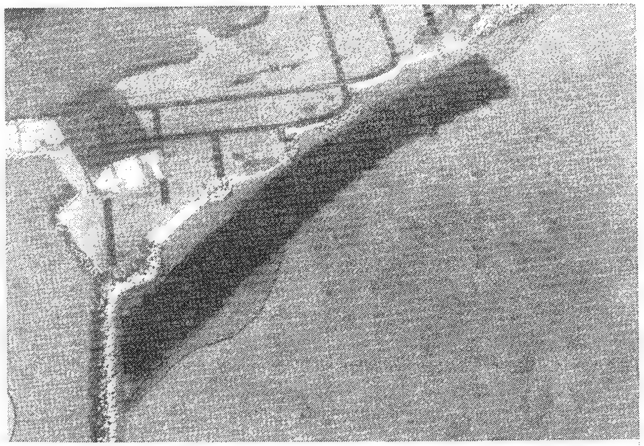
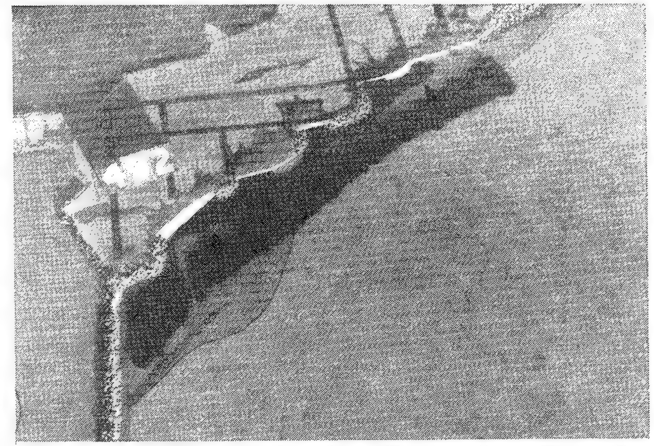


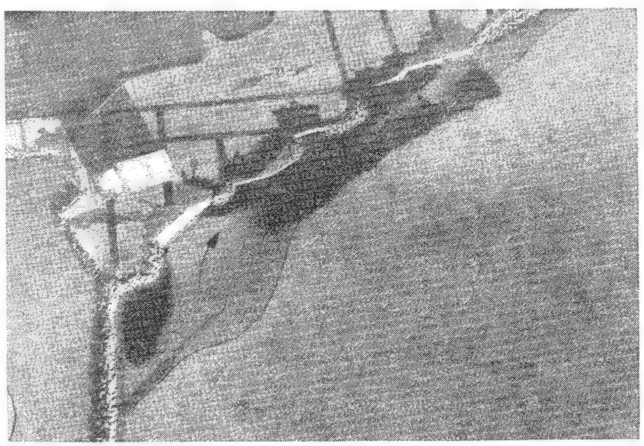
Photo 96. Progression of sediment tracer movement for Plan 7; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft



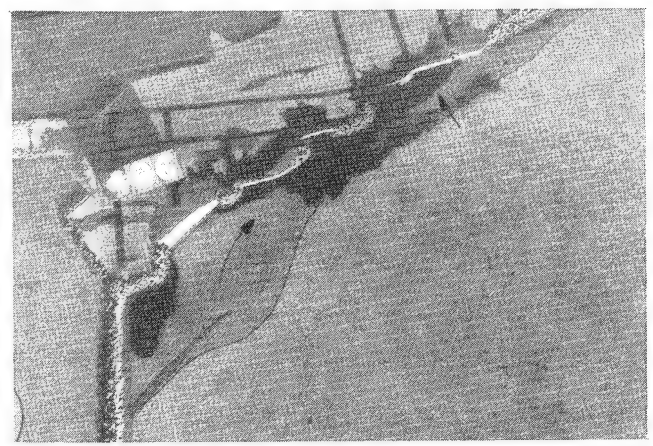
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 97. Progression of sediment tracer movement for Plan 7; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

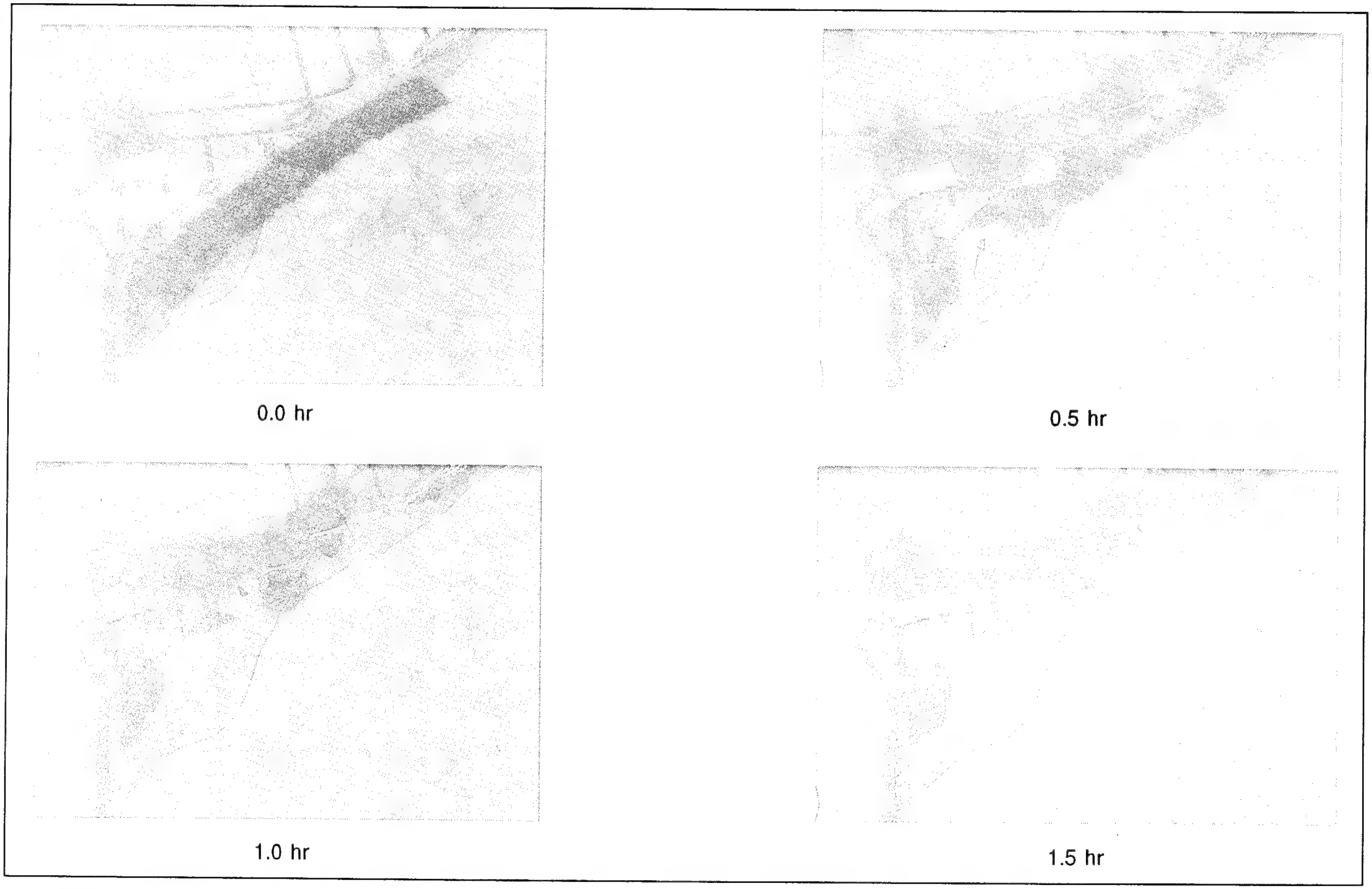


Photo 98. Progression of sediment tracer movement for Plan 7; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

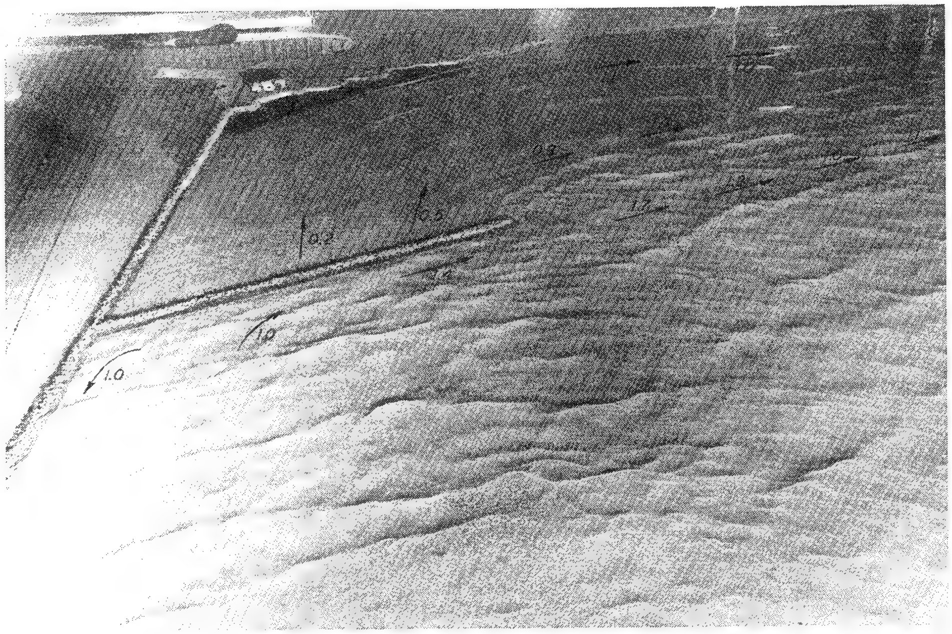


Photo 99. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 8; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

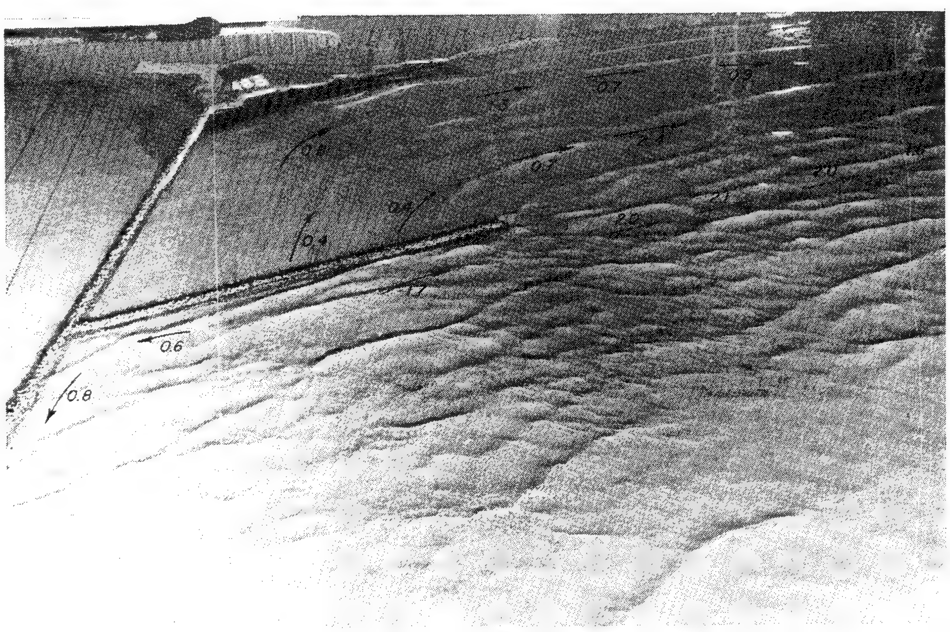


Photo 100. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 8; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft

Photo 101. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 8; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

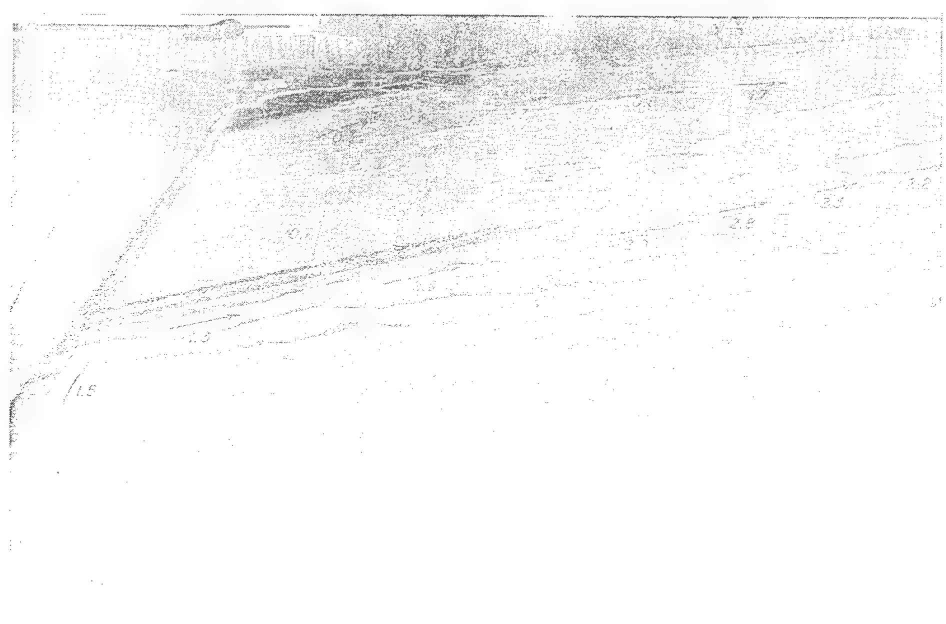


Photo 102. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 8; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

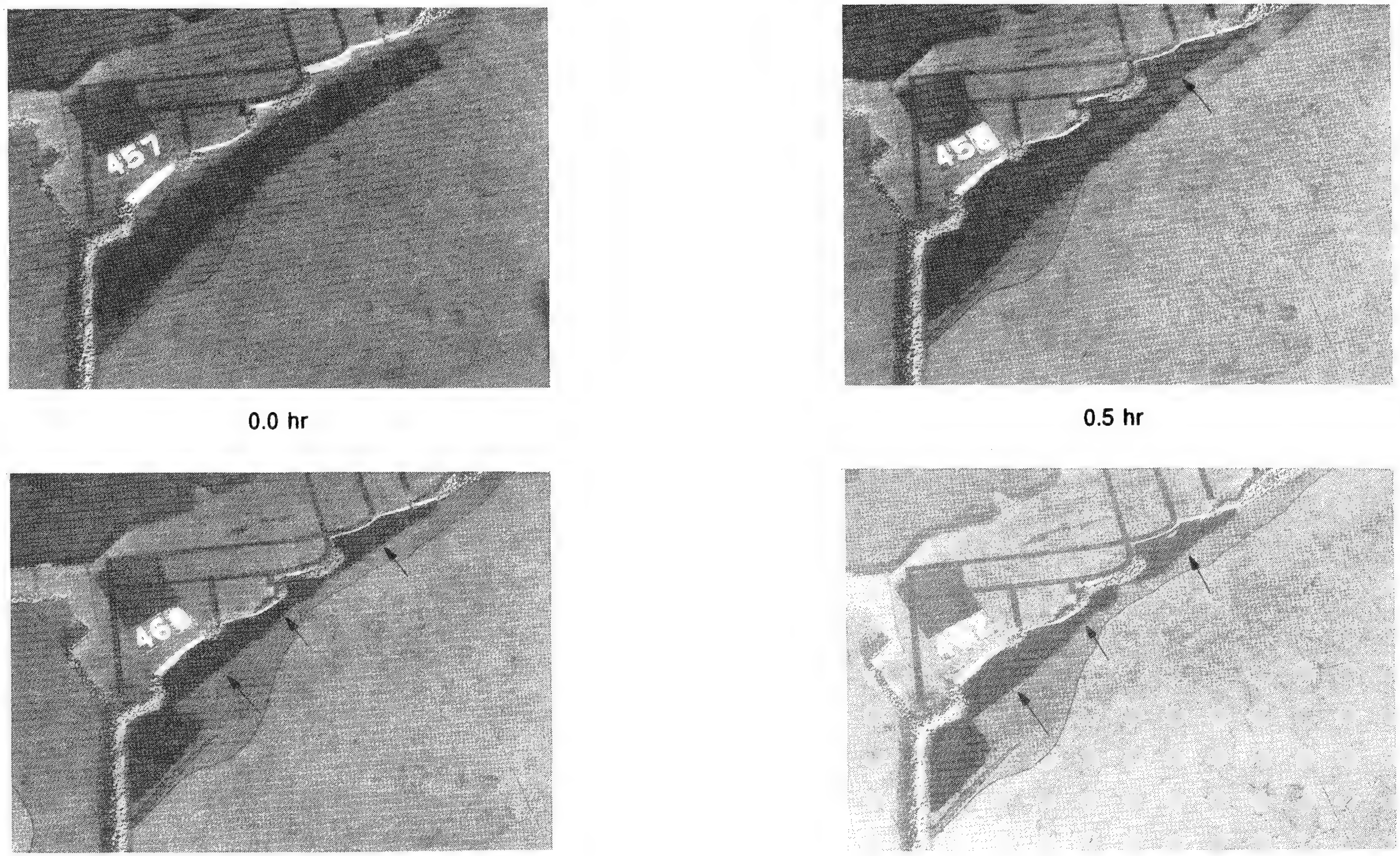


Photo 103. Progression of sediment tracer movement for Plan 8; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft (0-2.5 hr)

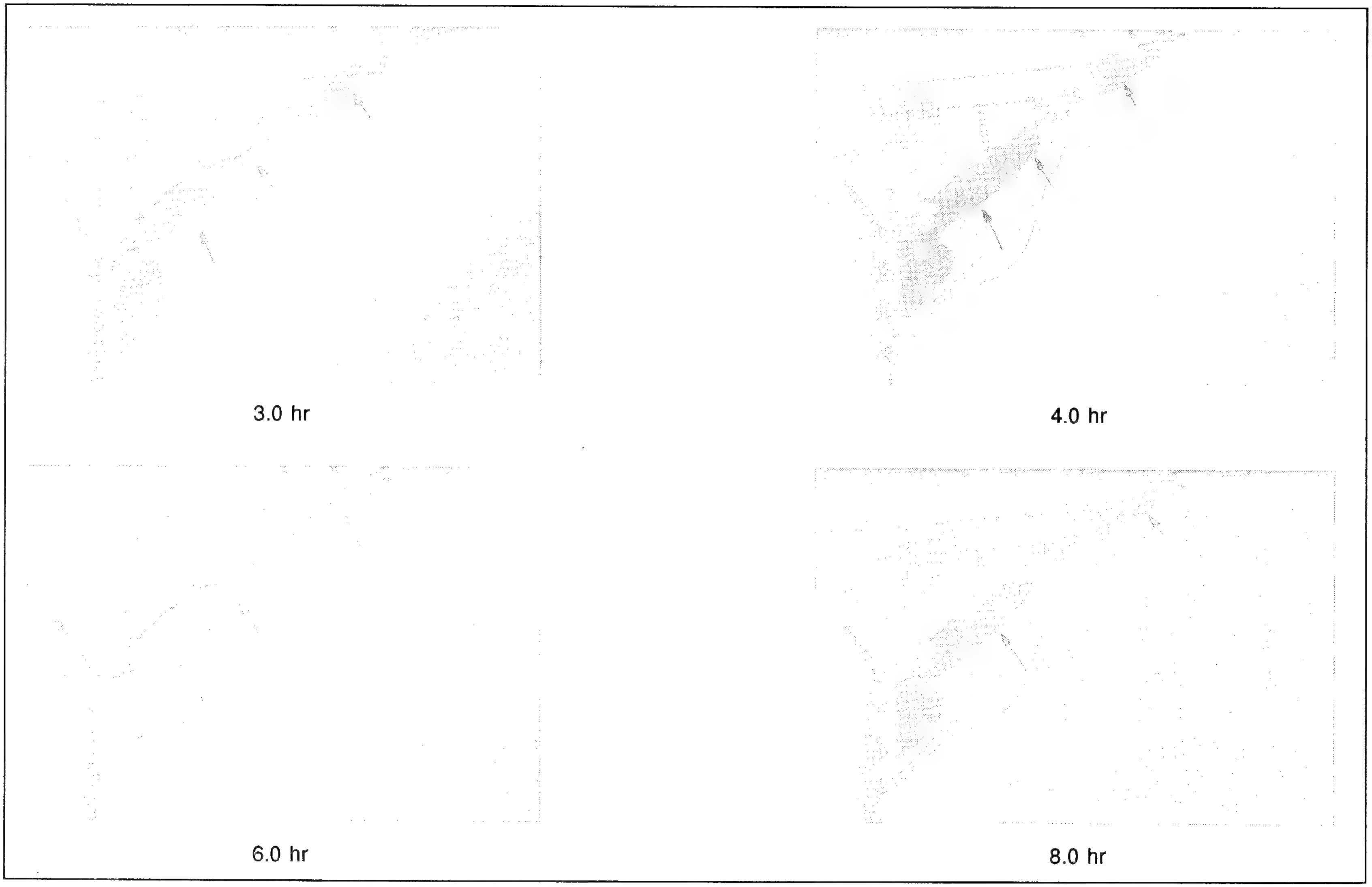


Photo 104. Progression of sediment tracer movement for Plan 8; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft (3-8 hr)

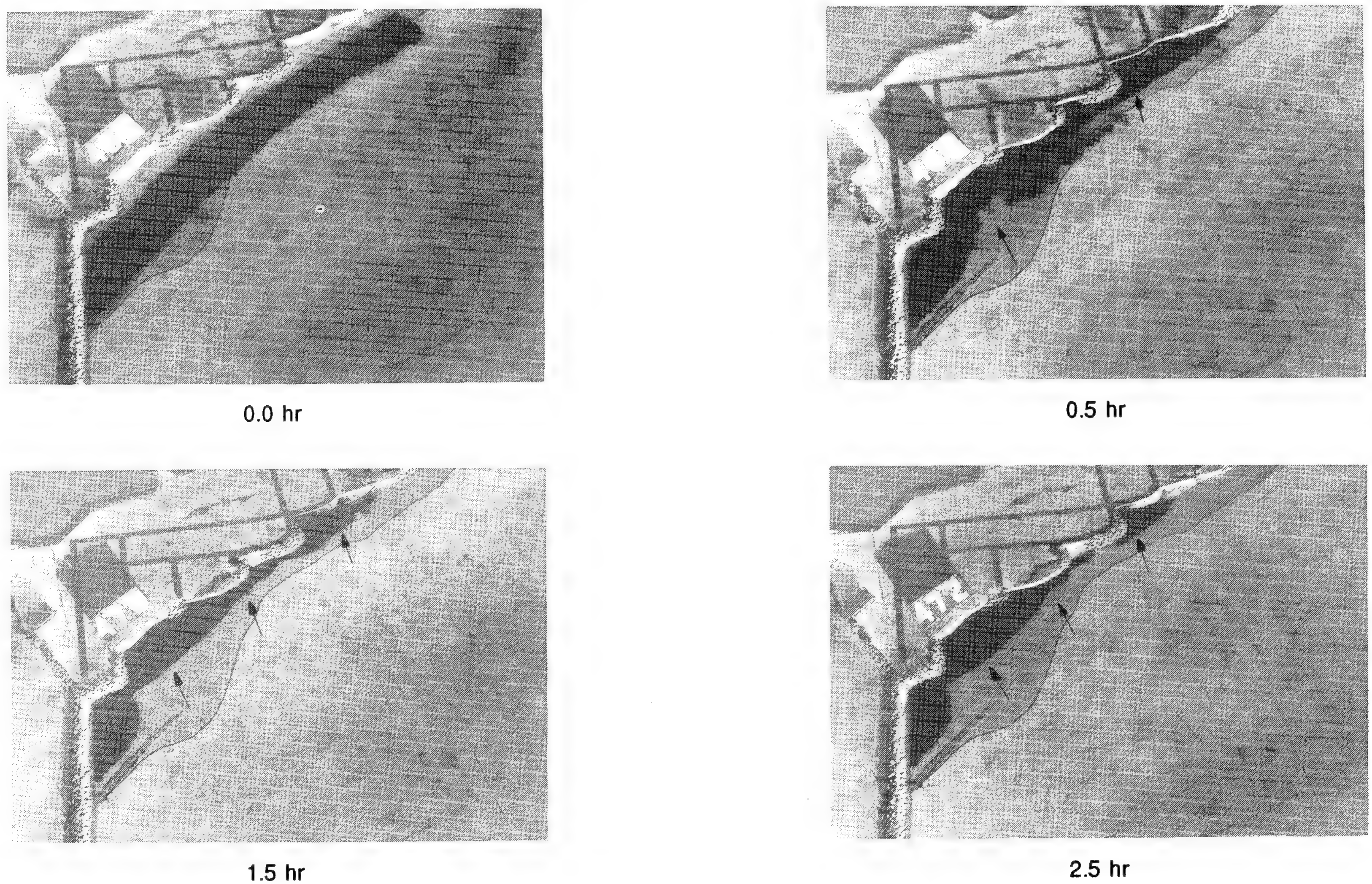


Photo 105: Progression of sediment tracer movement for Plan 8; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft

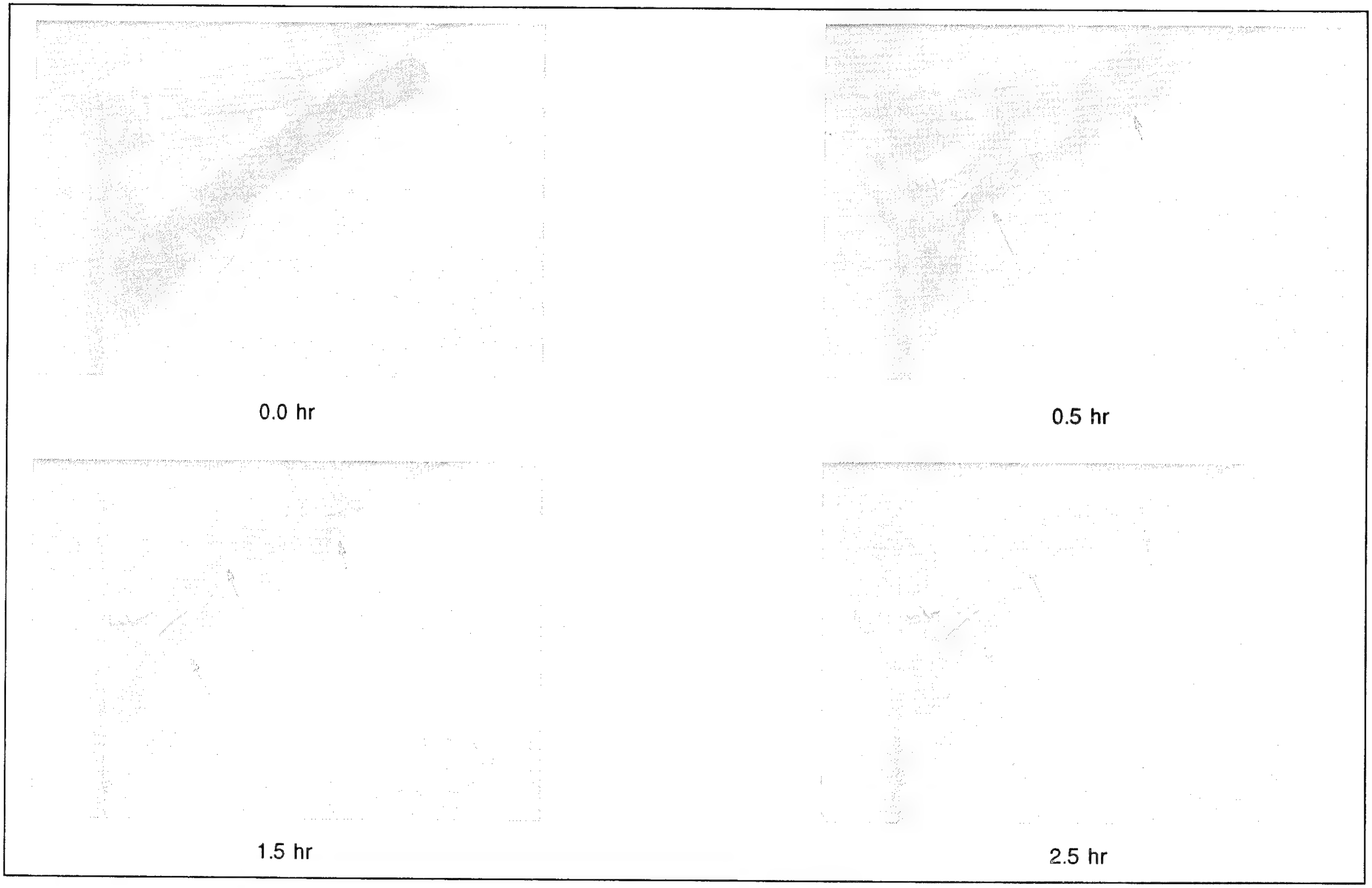
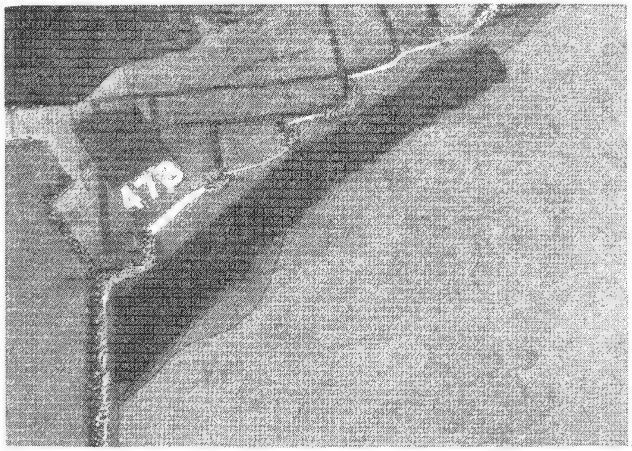
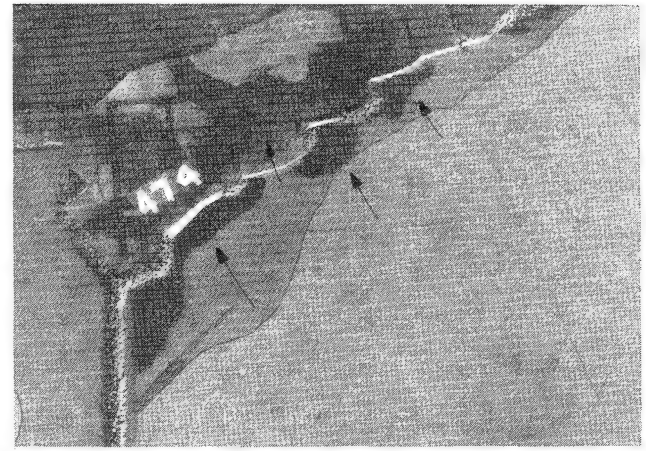


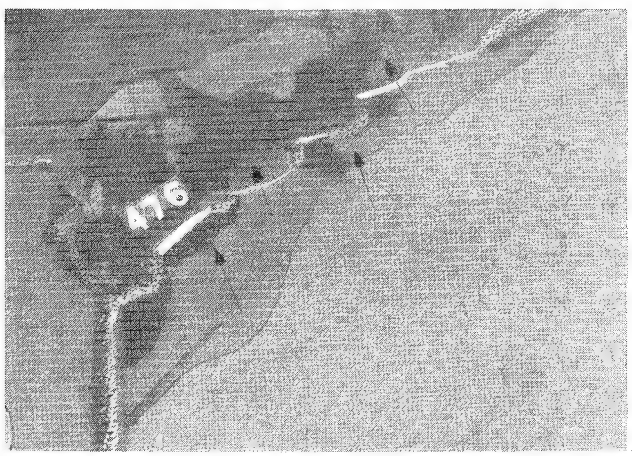
Photo 106. Progression of sediment tracer movement for Plan 8; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft



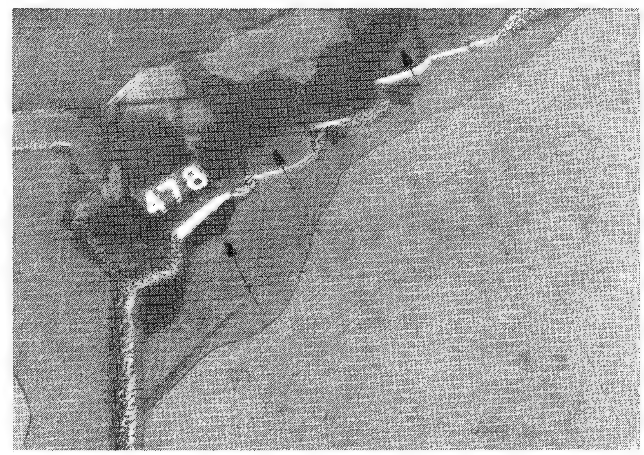
0.0 hr



0.5 hr



1.0 hr



1.5 hr

Photo 107. Progression of sediment tracer movement for Plan 8; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

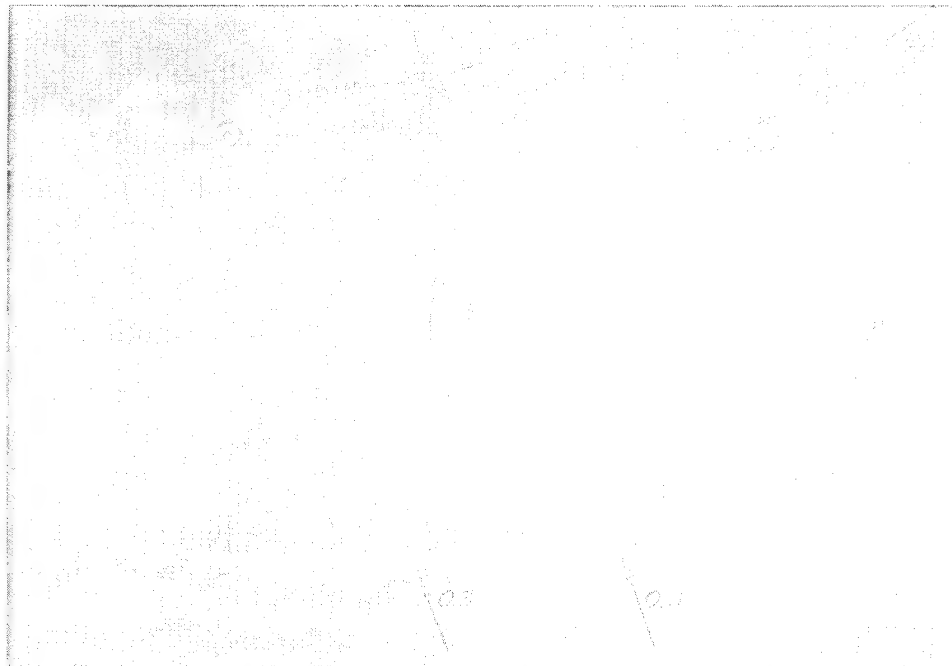


Photo 108. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 11-sec, 6-ft test waves from 101 deg; swl = +8.8 ft

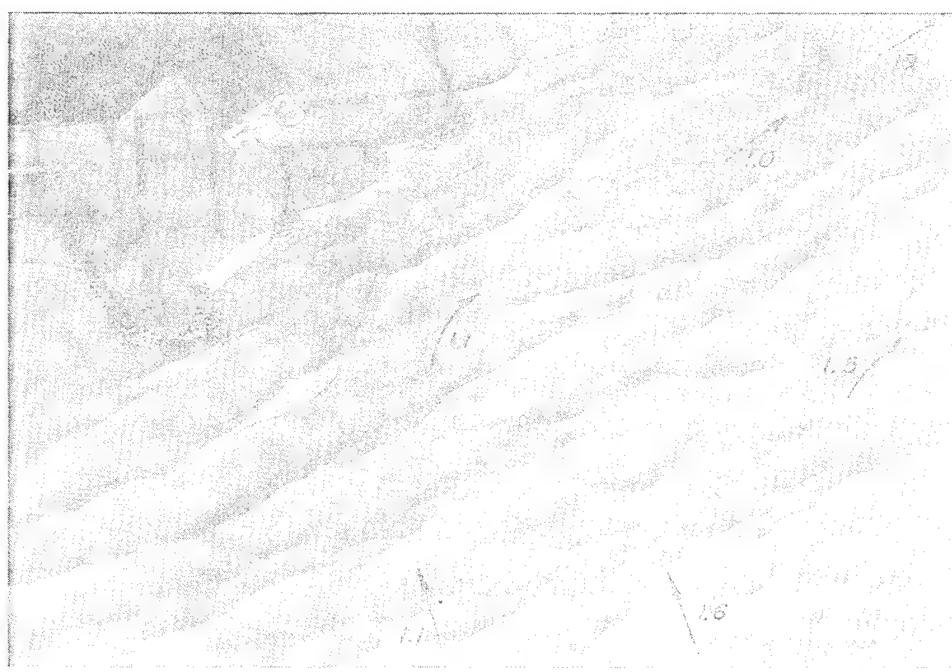


Photo 109. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

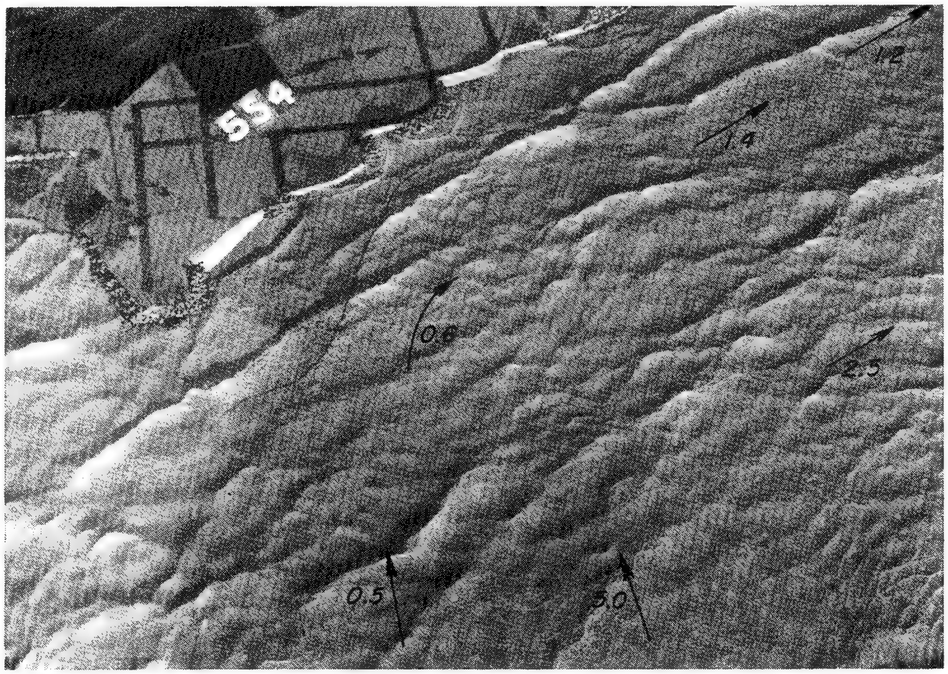


Photo 110. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 15-sec, 14-ft test waves from 101 deg; swl = +8.8 ft

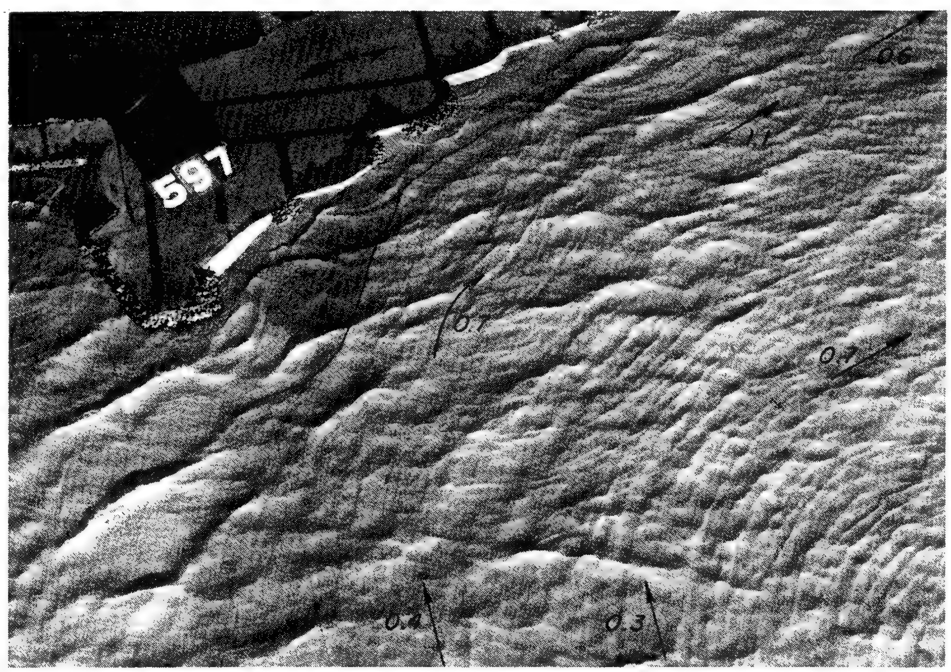


Photo 111. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 11-sec, 6-ft test waves from 88 deg; swl = +8.8 ft

Photo 112. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft

Photo 113. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 15-sec, 16-ft test waves from 88 deg; swl = +8.8 ft

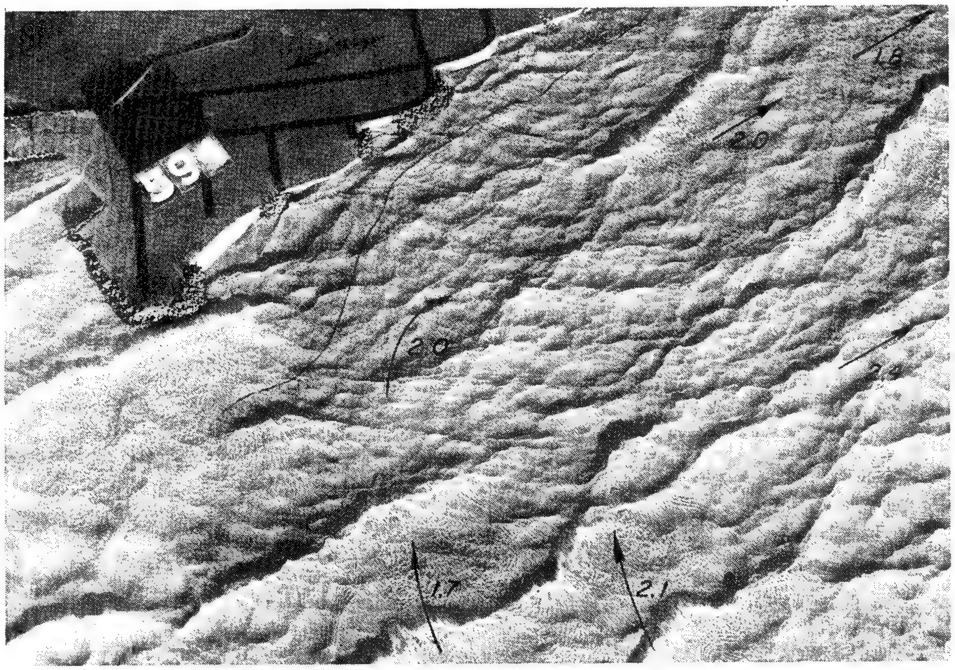


Photo 114. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft

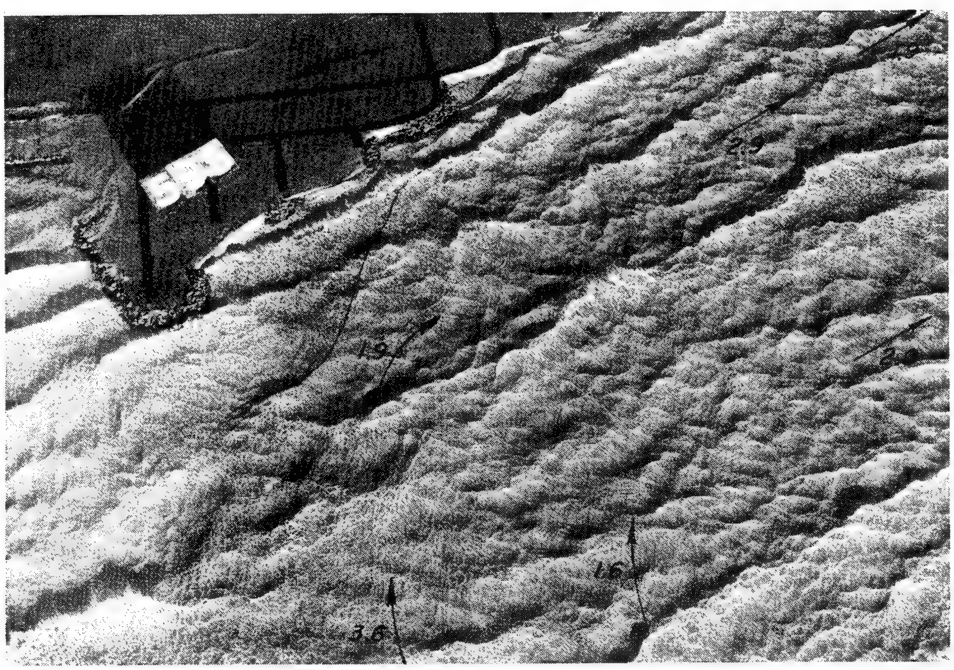


Photo 115. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 13-sec, 20-ft test waves from 88 deg; swl = +13.6 ft

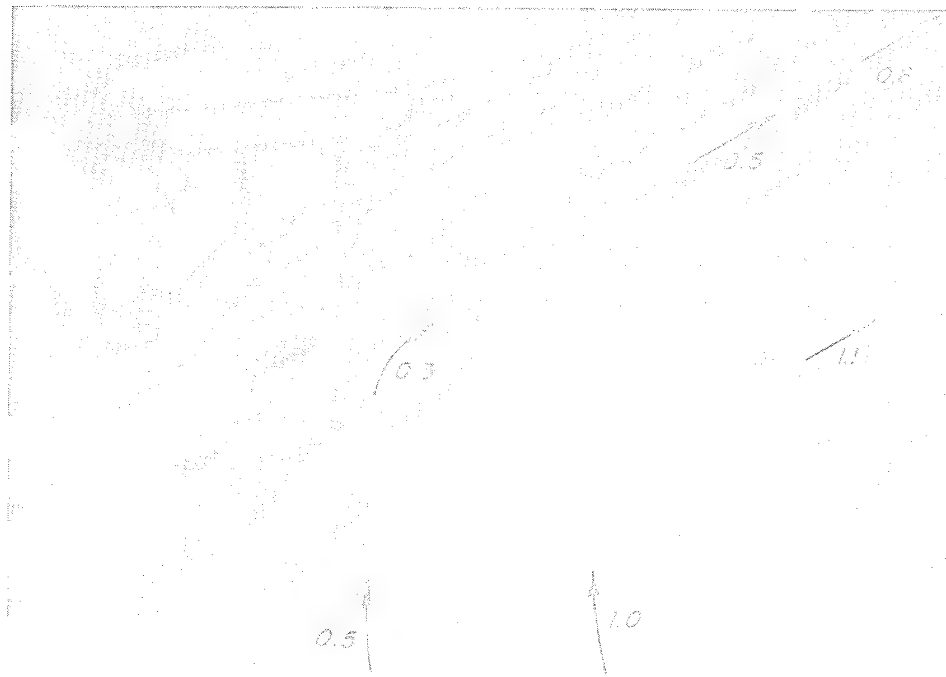


Photo 116. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 9-sec, 8-ft test waves from 75 deg; swl = +8.8 ft

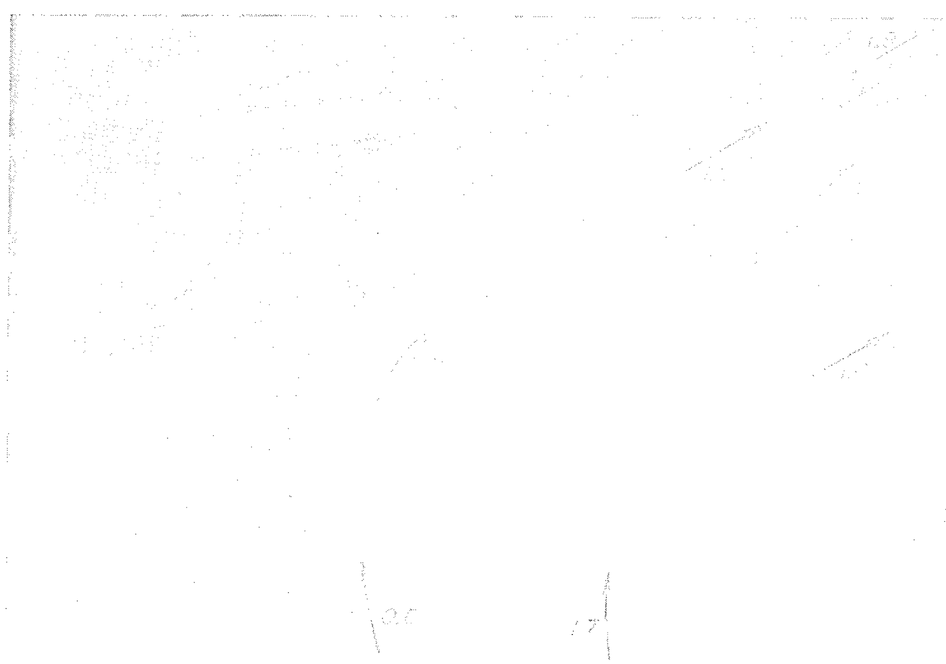


Photo 117. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft

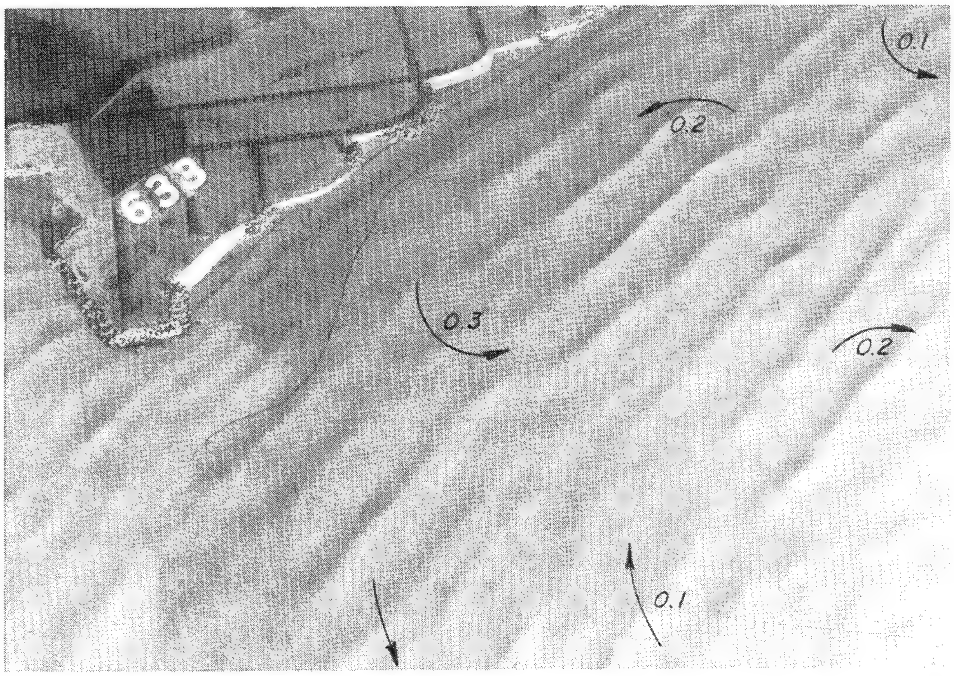


Photo 118. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft

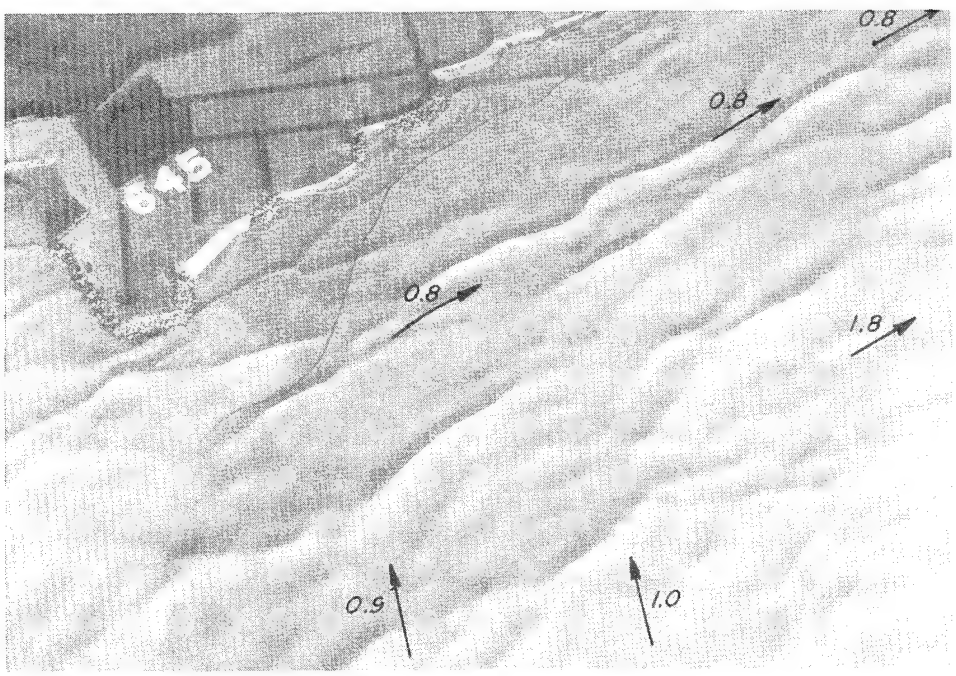


Photo 119. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft; 3,200-cfs river discharge

Photo 120. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft; 3,200-cfs river discharge

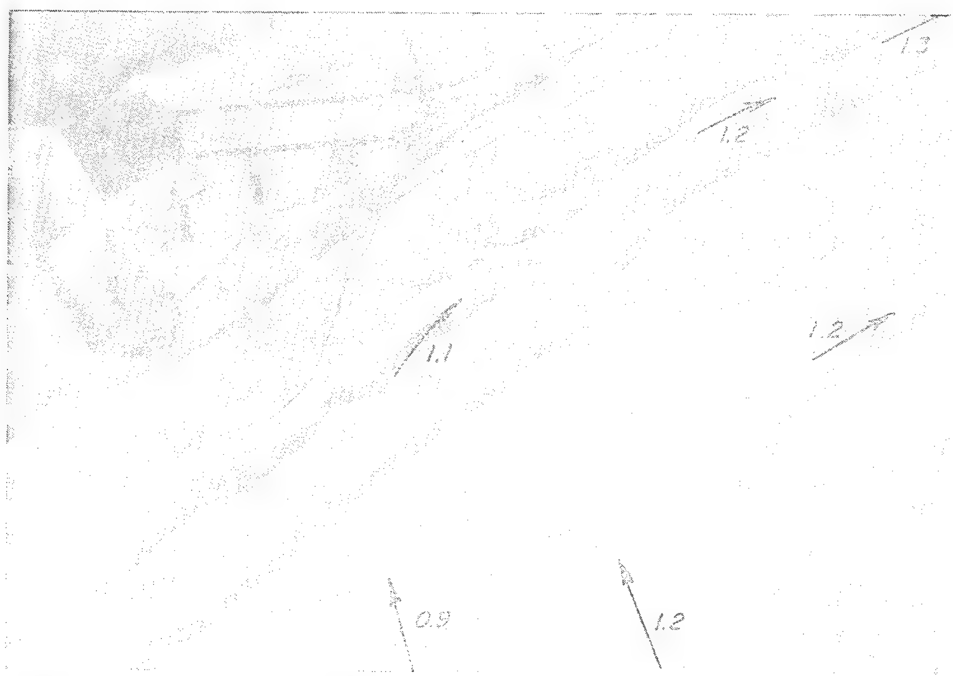


Photo 121. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft; 3,200-cfs river discharge

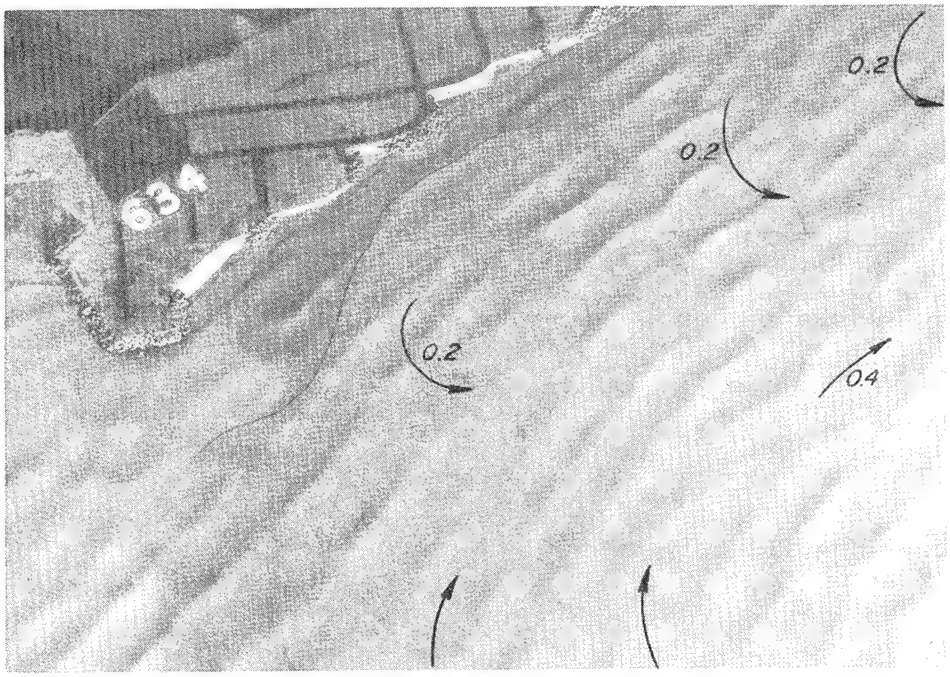


Photo 122. Typical wave patterns, current patterns, and current magnitudes (prototype feet per second) for Plan 9; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft; 3,200-cfs river discharge

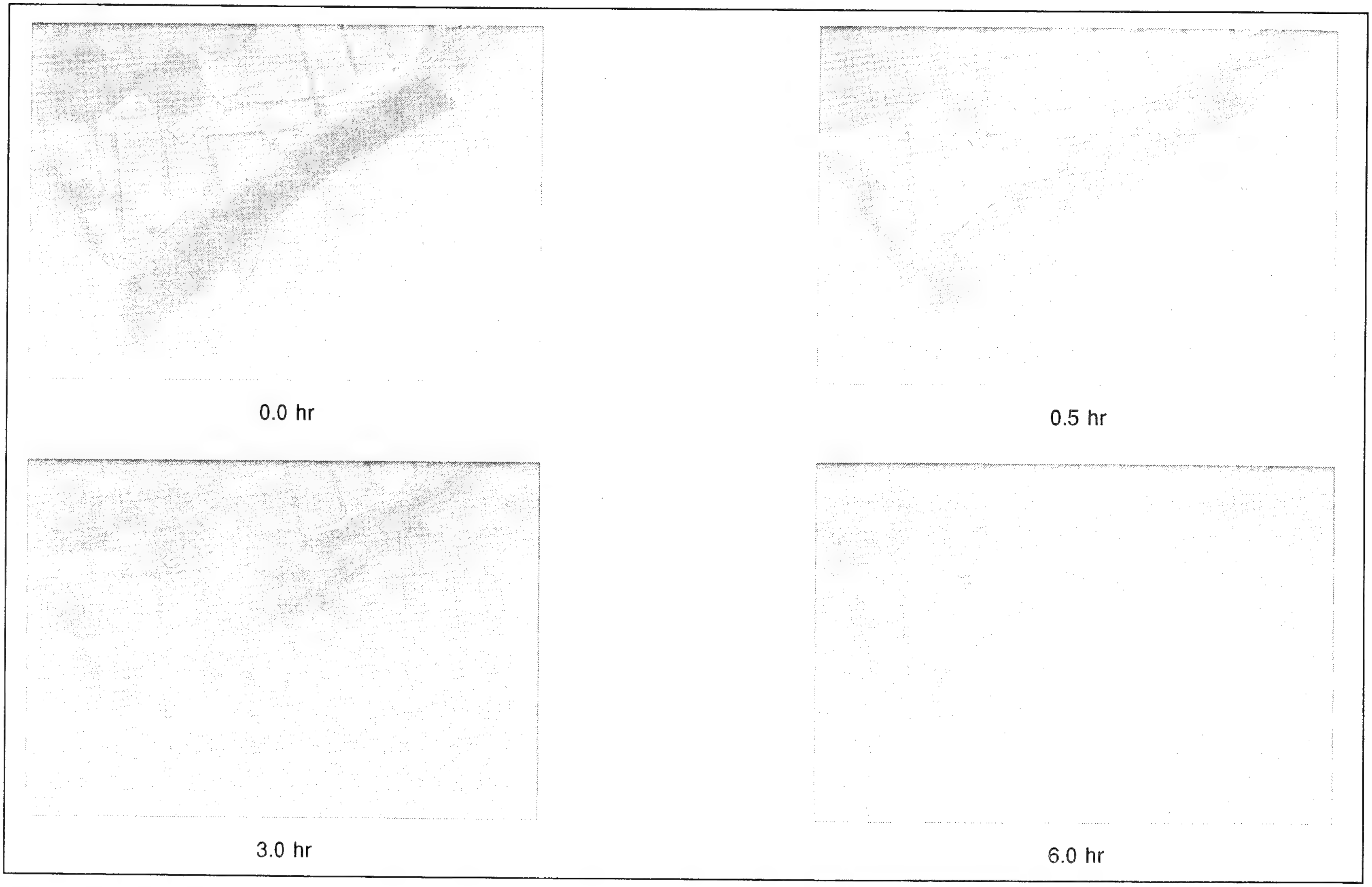
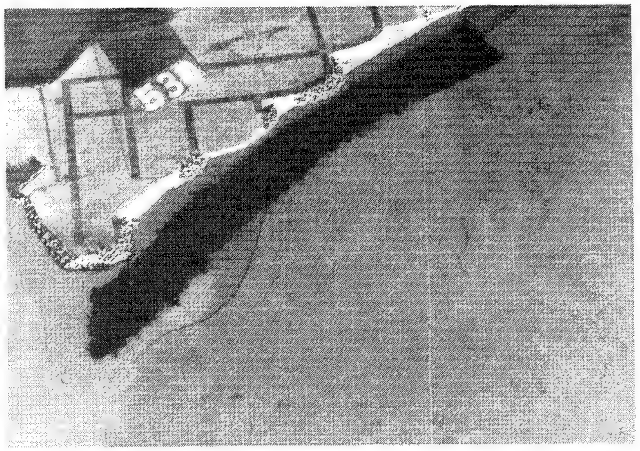
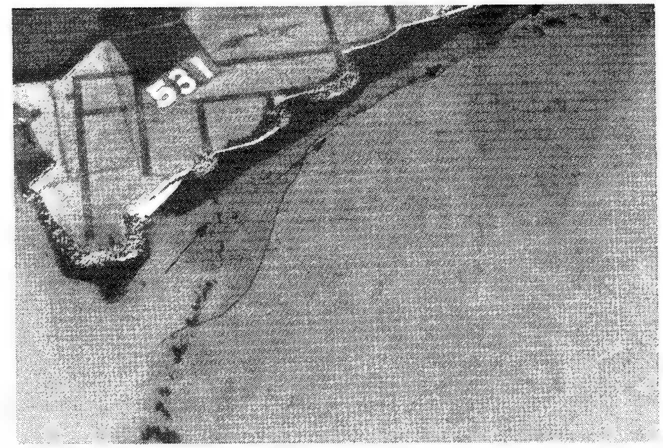


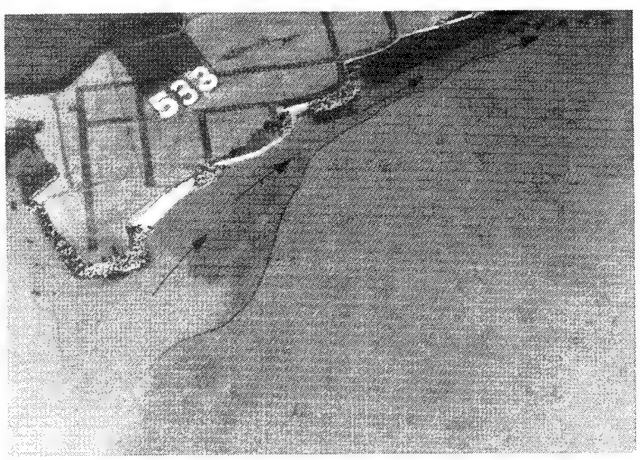
Photo 123. Progression of sediment tracer movement for Plan 9; 11-sec, 6-ft test waves from 101 deg; swl = +8.8 ft



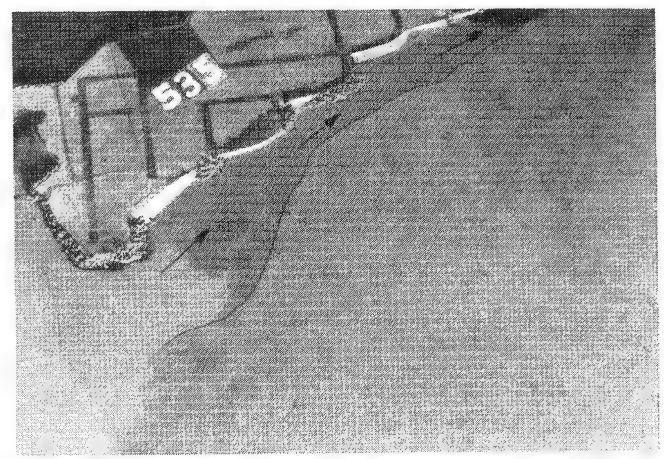
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 124. Progression of sediment tracer movement for Plan 9; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft

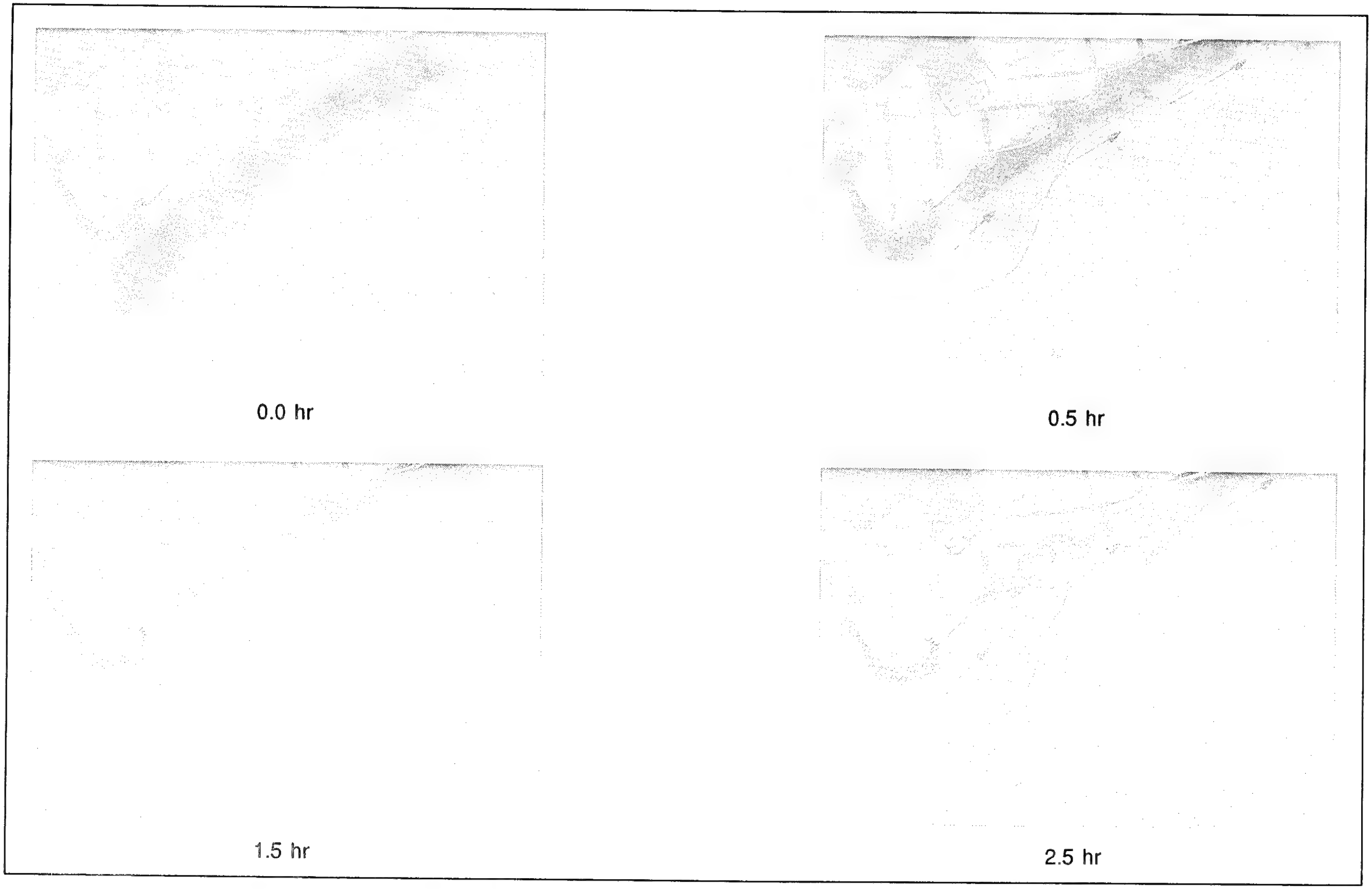
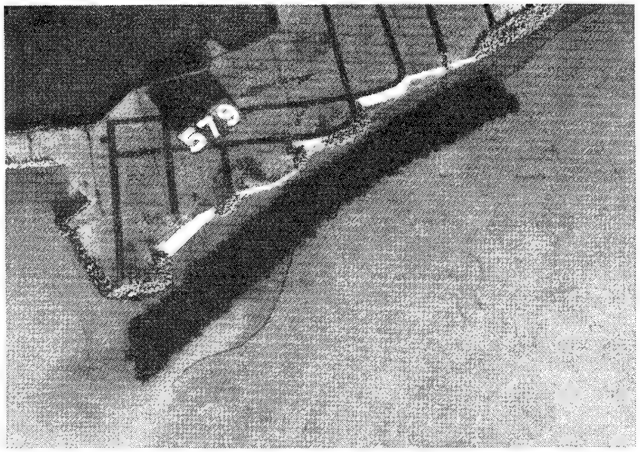
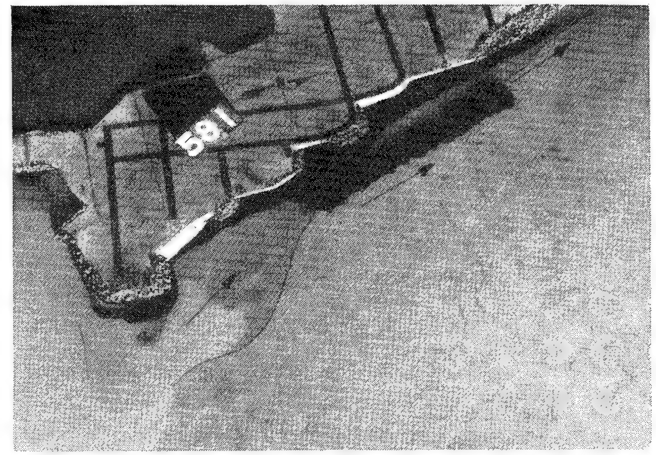


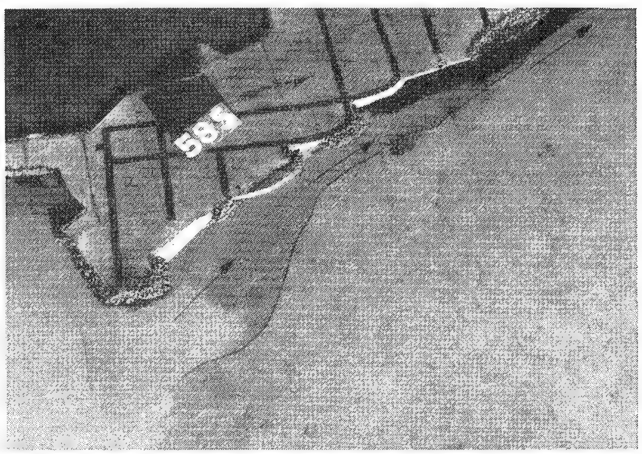
Photo 125. Progression of sediment tracer movement for Plan 9; 15-sec, 14-ft test waves from 101 deg; swl = +8.8 ft



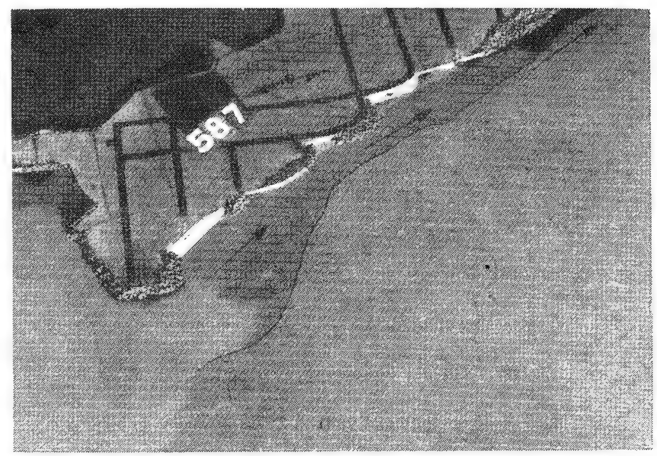
0.0 hr



1.0 hr



3.0 hr



5.0 hr

Photo 126. Progression of sediment tracer movement for Plan 9; 11-sec, 6-ft test waves from 88 deg; swl = +8.8 ft

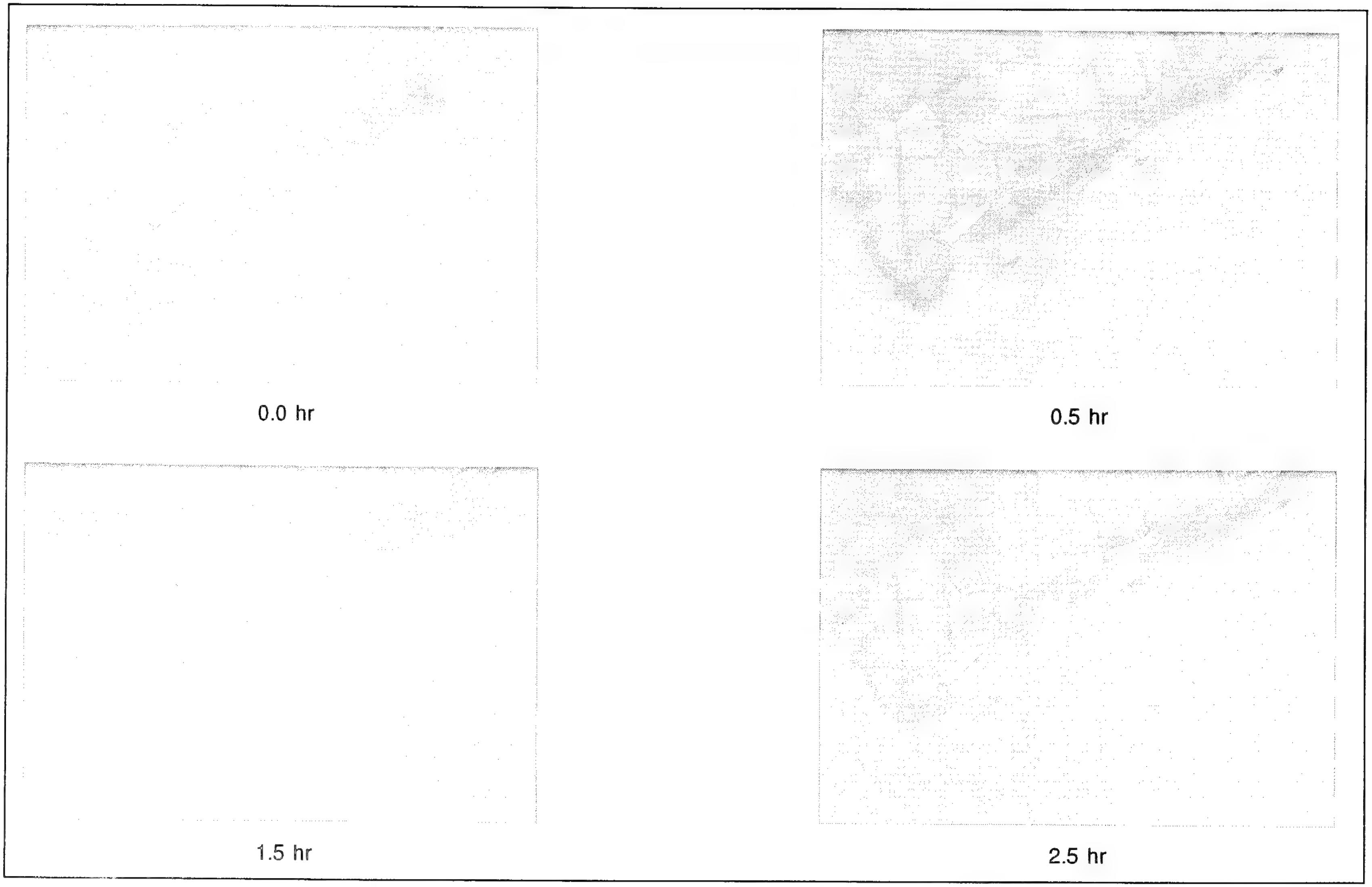
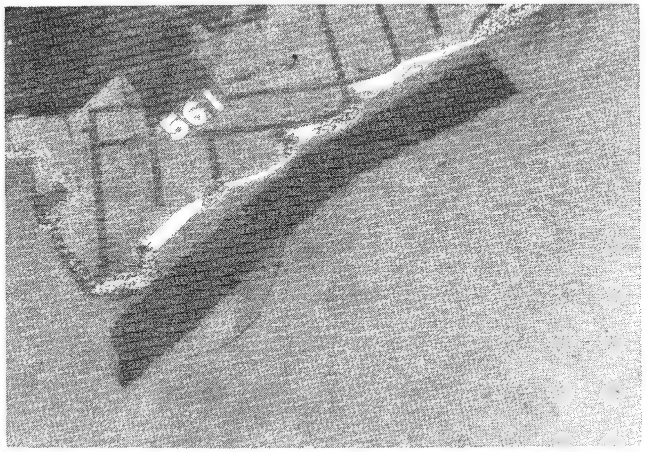
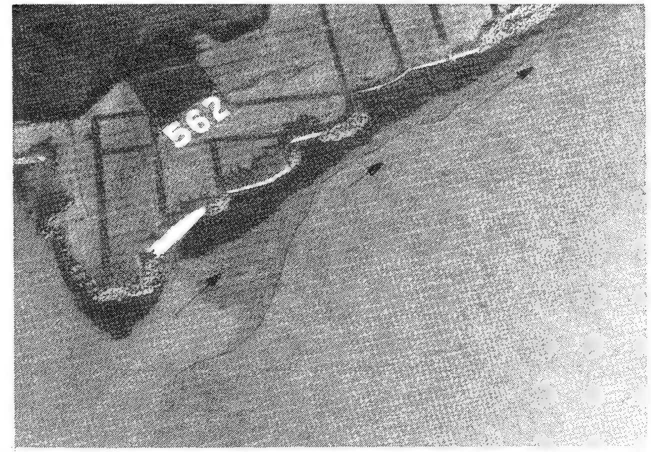


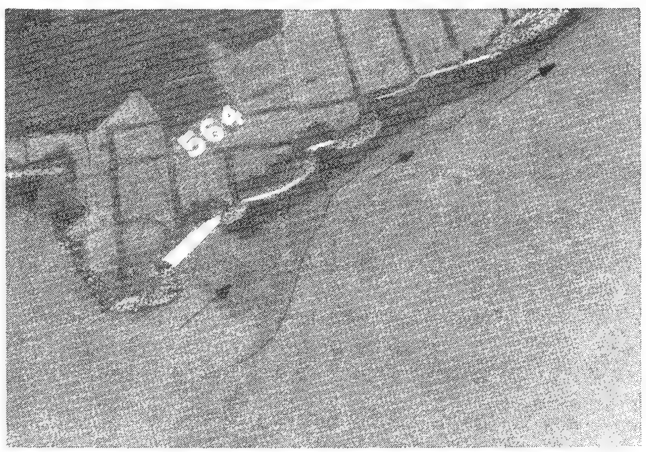
Photo 127. Progression of sediment tracer movement for Plan 9; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft



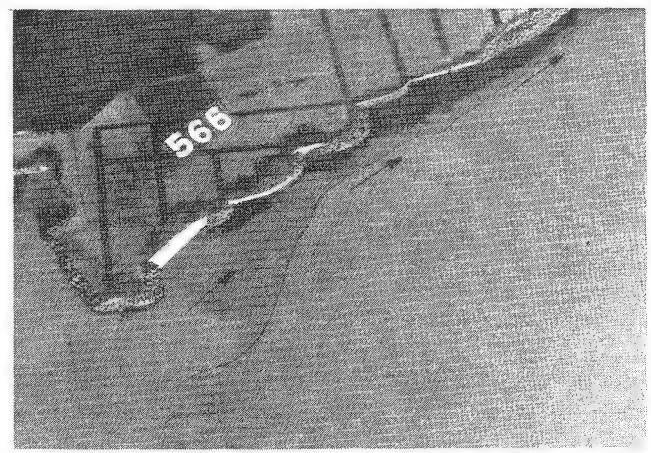
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 128. Progression of sediment tracer movement for Plan 9; 15-sec, 16-ft test waves from 88 deg; swl = +8.8 ft

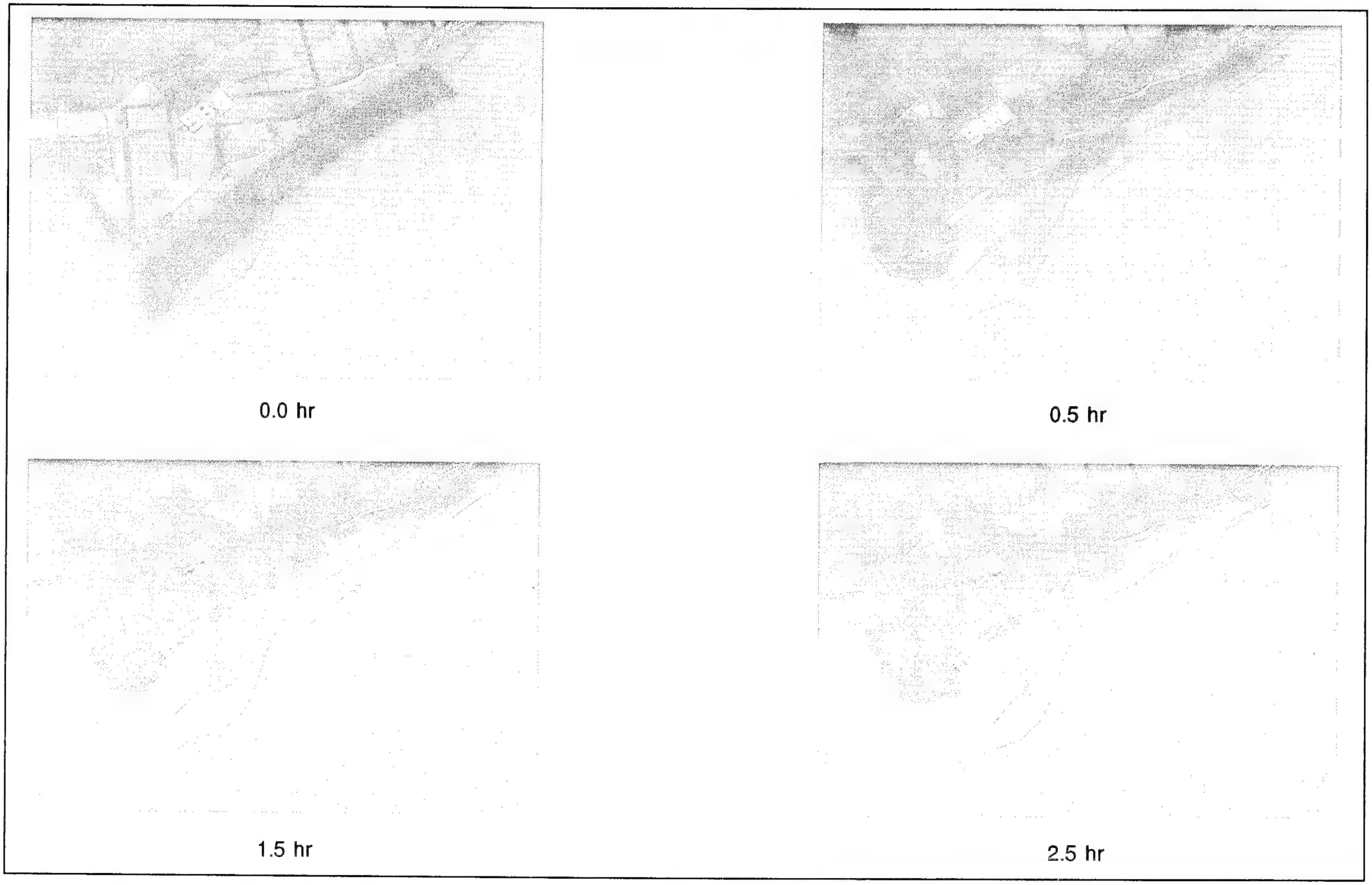
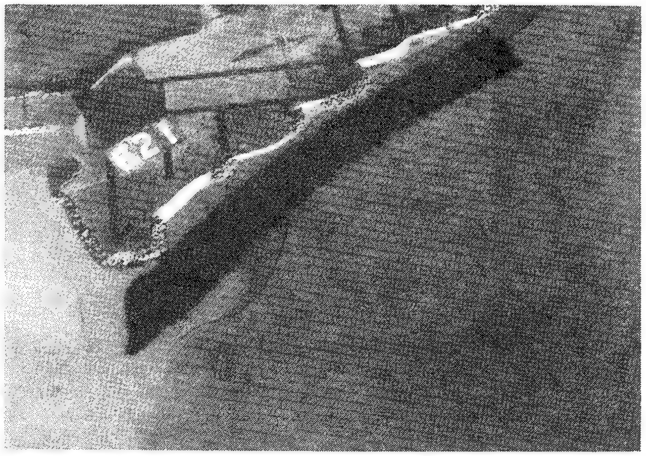
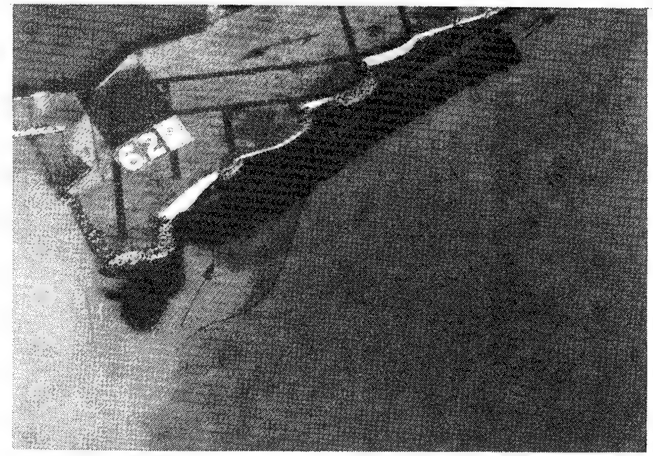


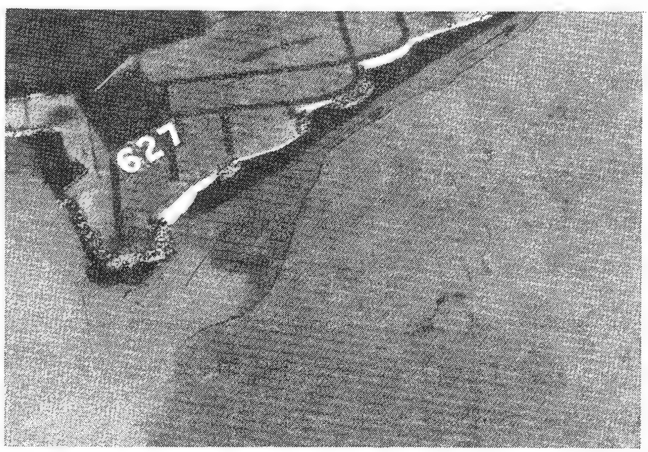
Photo 129. Progression of sediment tracer movement for Plan 9; 15-sec, 18-ft test waves from 88 deg; swl = +12.0 ft



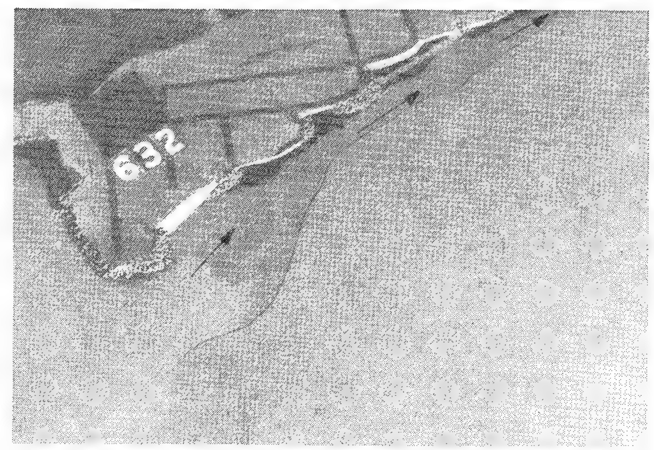
0.0 hr



0.5 hr



3.0 hr



8.0 hr

Photo 130. Progression of sediment tracer movement for Plan 9; 9-sec, 8-ft test waves from 75 deg; swl = +8.8 ft

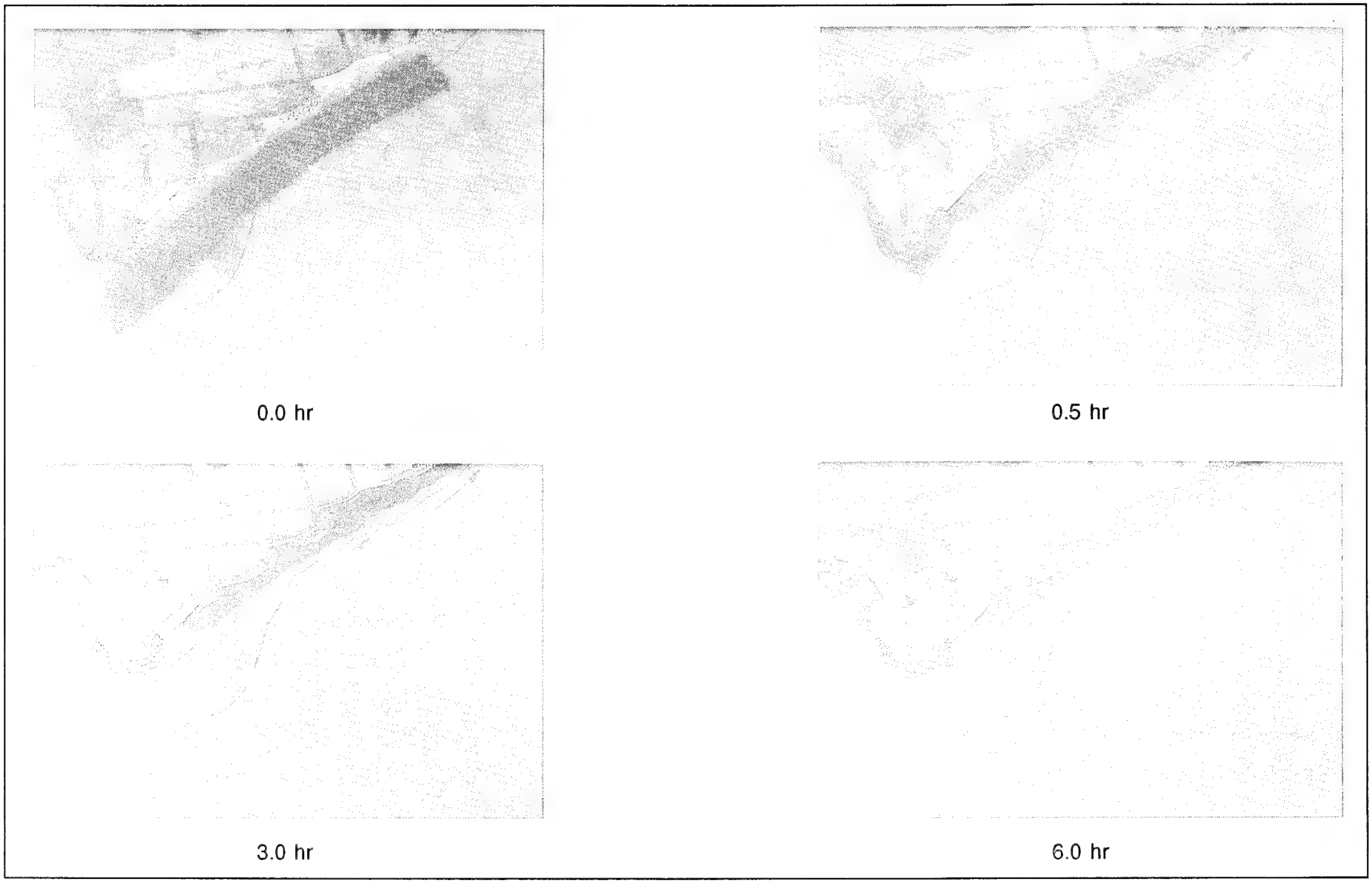
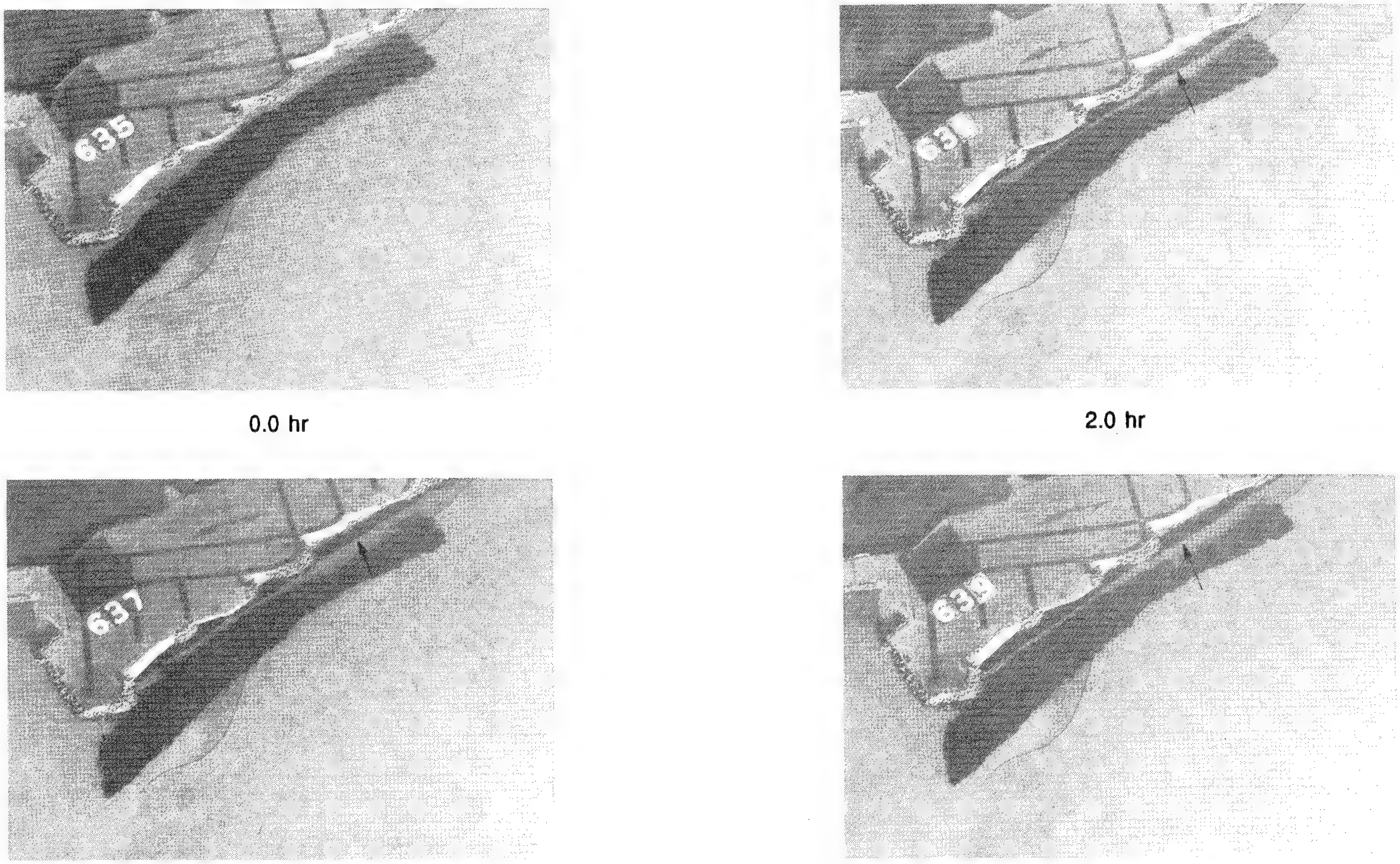


Photo 131. Progression of sediment tracer movement for Plan 9; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft



0.0 hr

2.0 hr

4.0 hr

8.0 hr

Photo 132. Progression of sediment tracer movement for Plan 9; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft

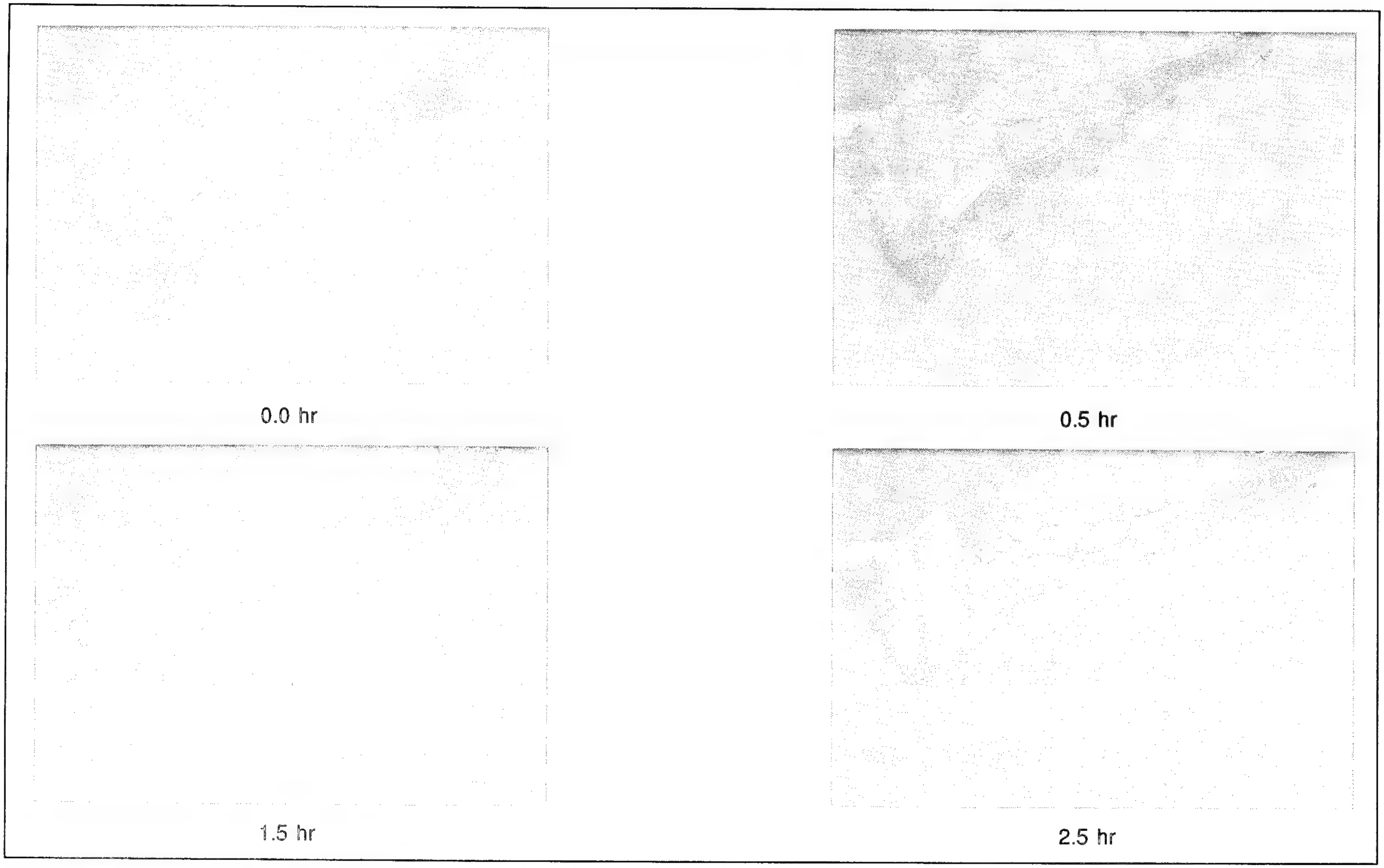
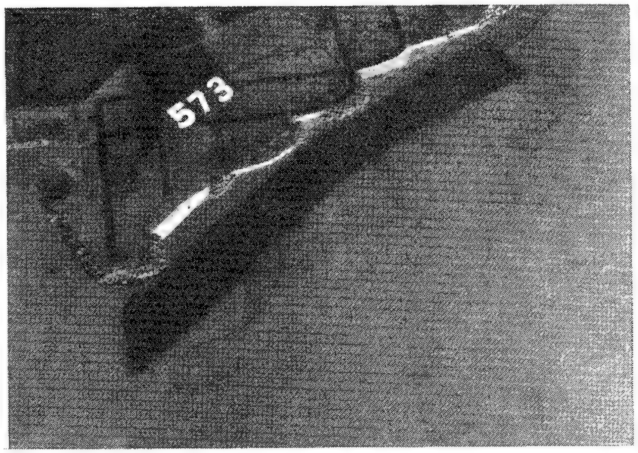
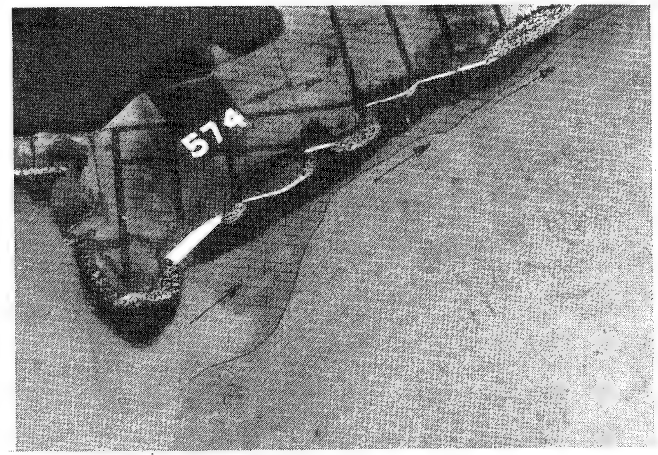


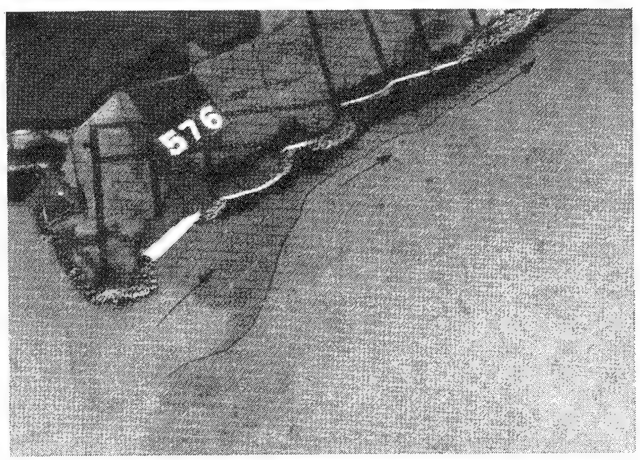
Photo 133. Progression of sediment tracer movement for Plan 9; 13-sec, 12-ft test waves from 101 deg; swl = +8.8 ft; 3,200-cfs river discharge



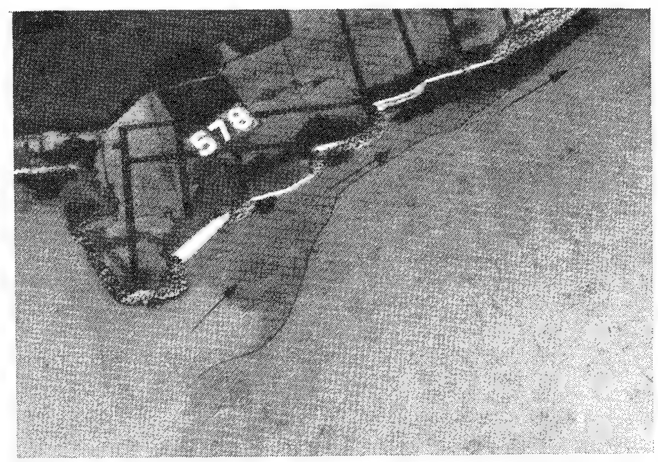
0.0 hr



0.5 hr



1.5 hr



2.5 hr

Photo 134. Progression of sediment tracer movement for Plan 9; 13-sec, 18-ft test waves from 88 deg; swl = +8.8 ft; 3,200-cfs river discharge

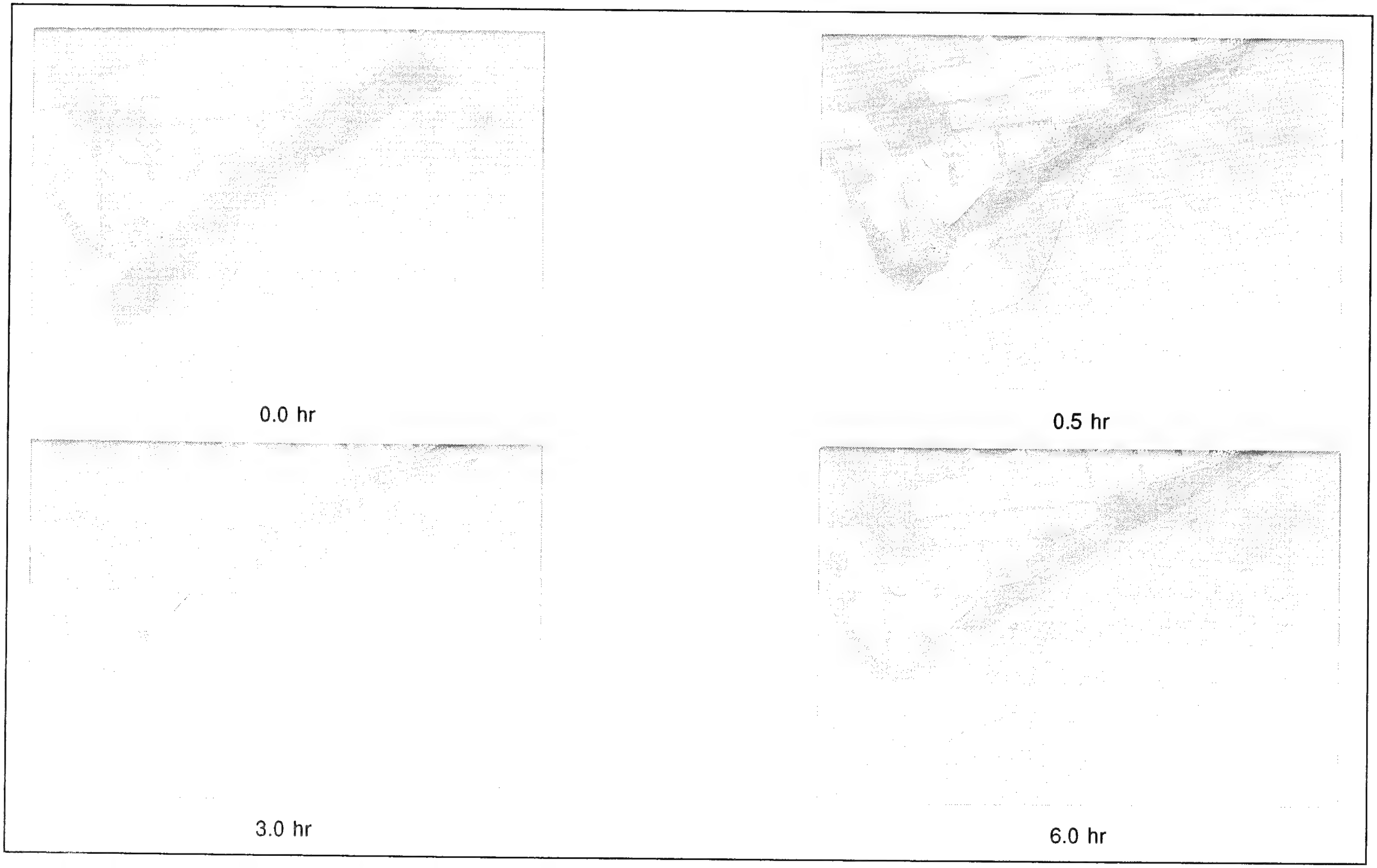
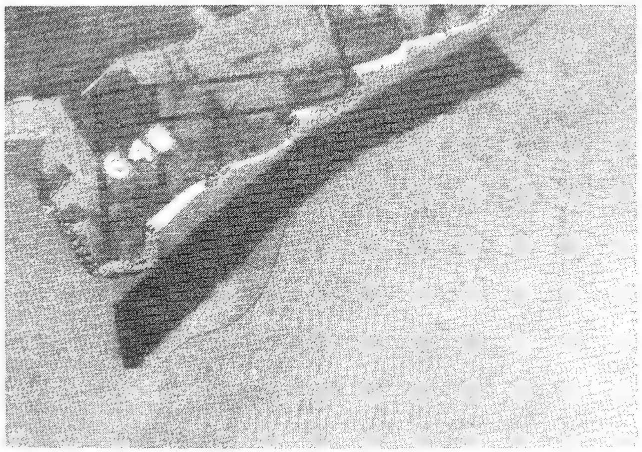
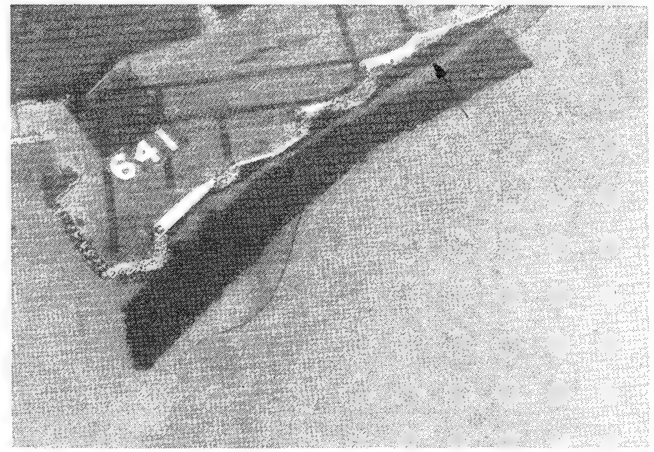


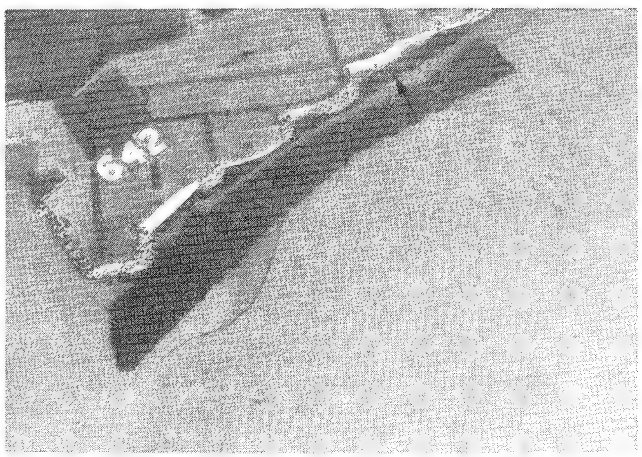
Photo 135. Progression of sediment tracer movement for Plan 9; 11-sec, 14-ft test waves from 75 deg; swl = +8.8 ft; 3,200-cfs river discharge



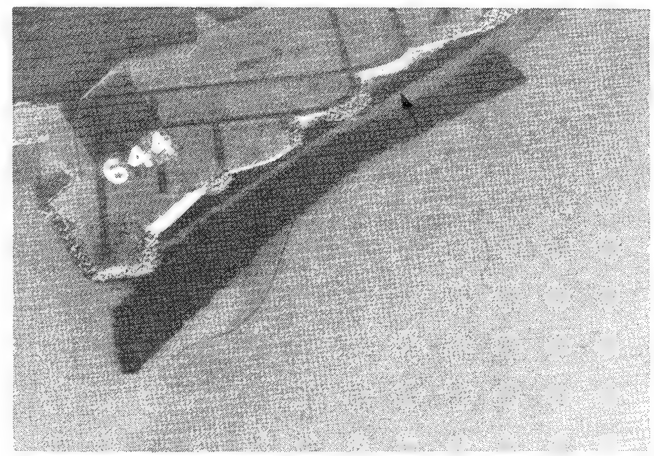
0.0 hr



2.0 hr



4.0 hr



8.0 hr

Photo 136. Progression of sediment tracer movement for Plan 9; 7-sec, 4-ft test waves from 56 deg; swl = +8.8 ft

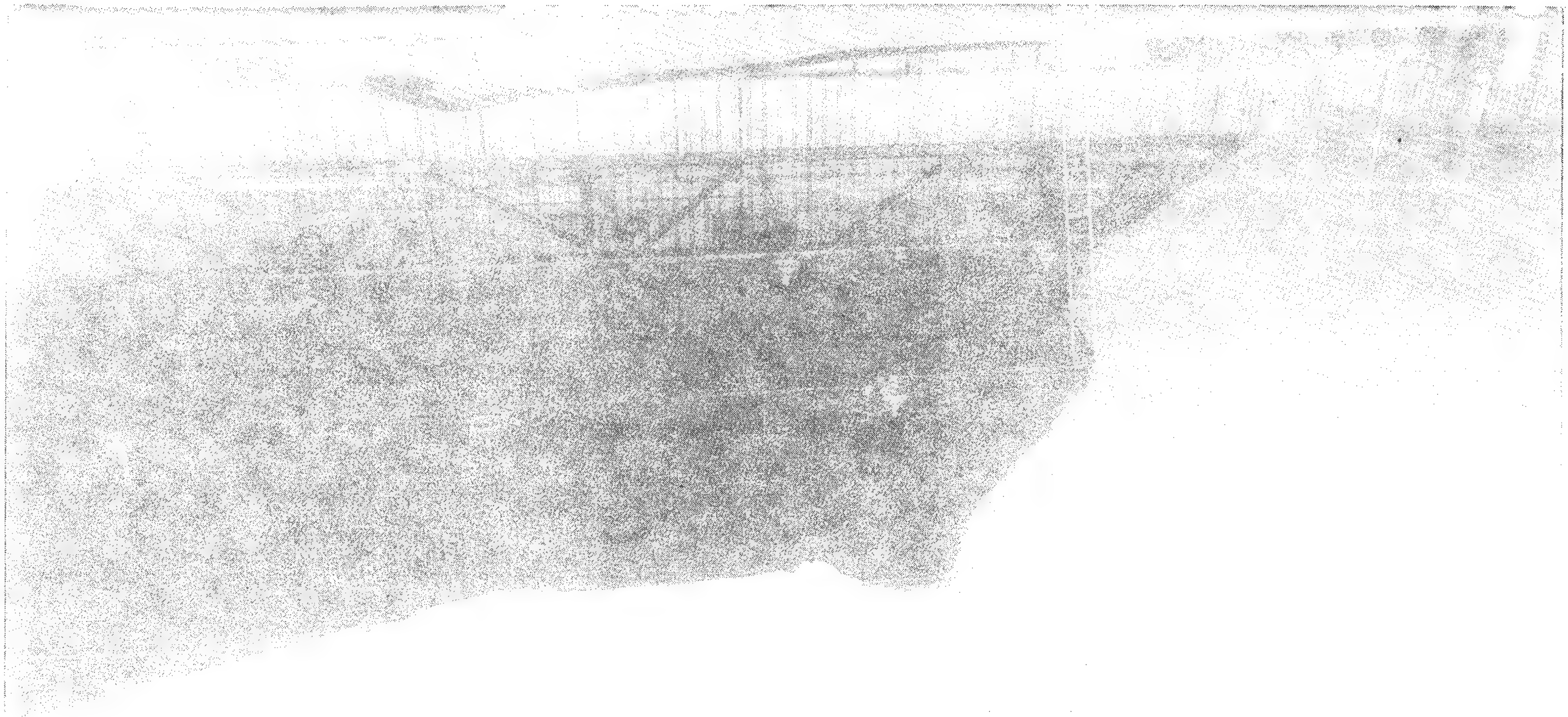
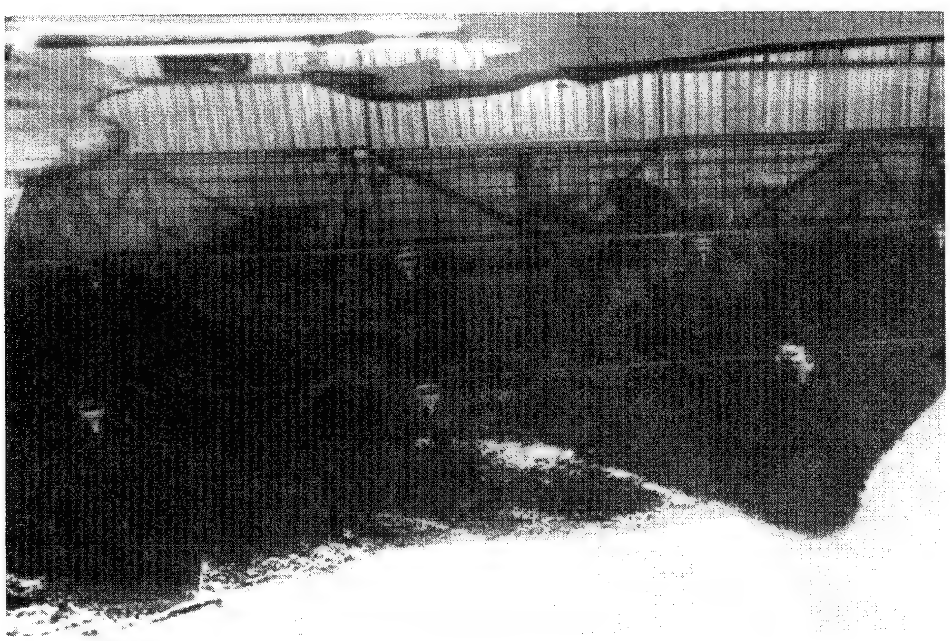


Photo 137. Overall view of pre-breakwater conditions prior to model testing

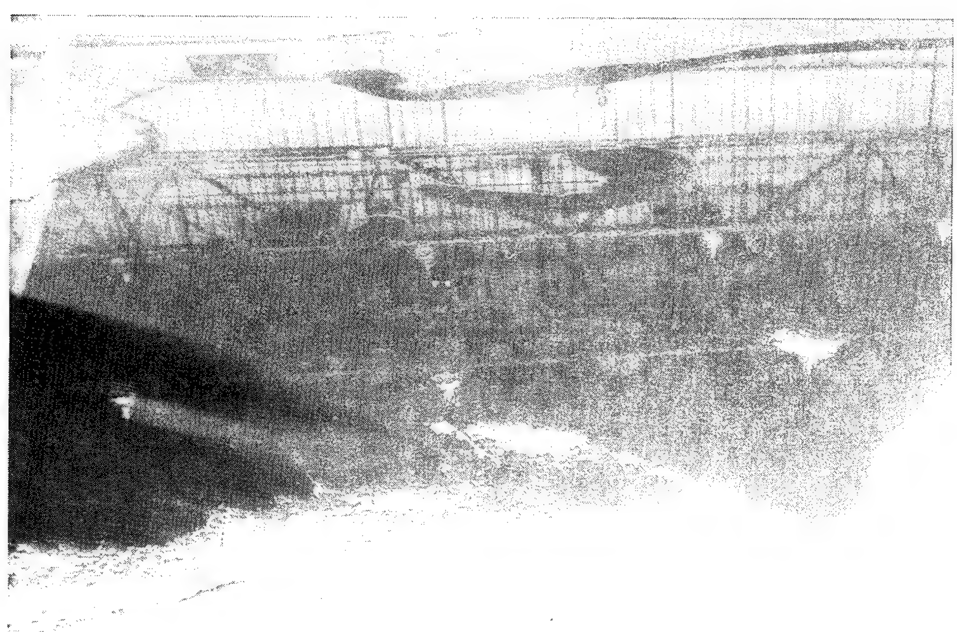
5 hr



10 hr

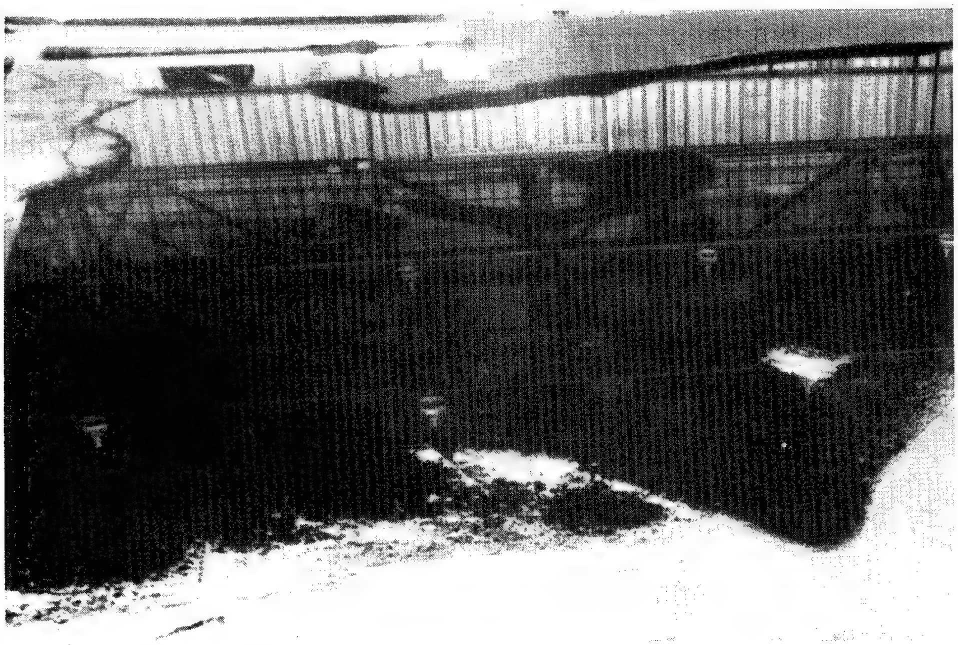
Photo 138. Progression of sediment tracer movement at Camp Ellis Beach for pre-breakwater conditions (5-10 hr)

13 hr

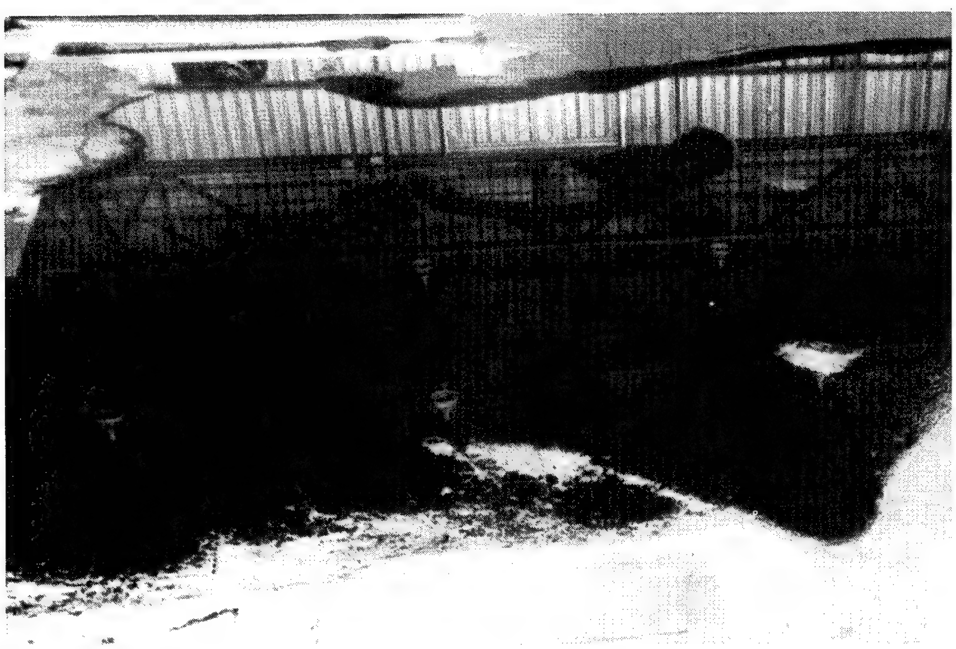


16 hr

Photo 139. Progression of sediment tracer movement at Camp Ellis Beach for pre-breakwater conditions (13-16 hr)



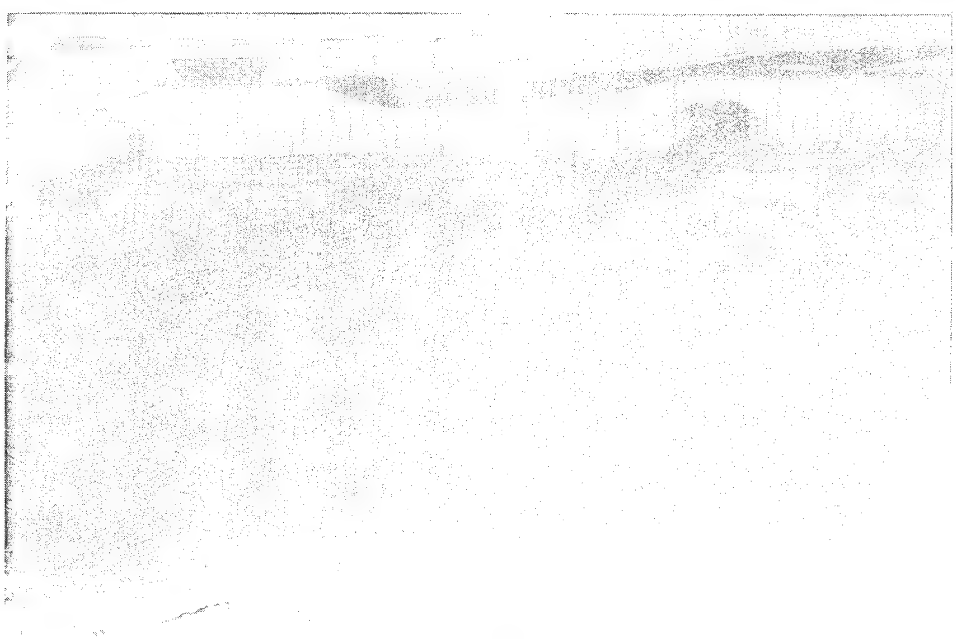
19 hr



22 hr

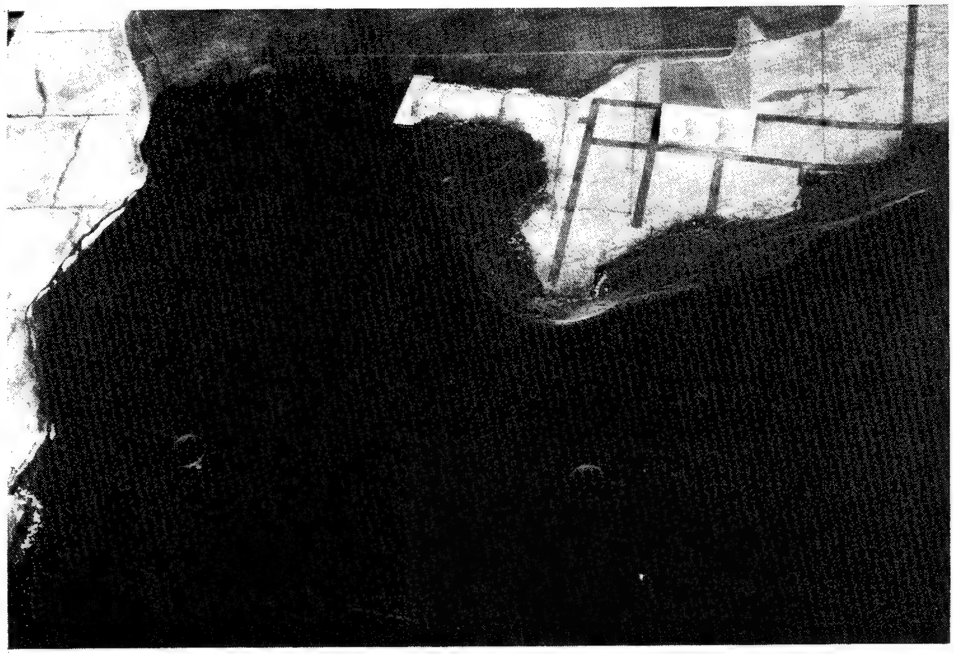
Photo 140. Progression of sediment tracer movement at Camp Ellis Beach for pre-breakwater conditions (19-22 hr)

27 hr



32 hr

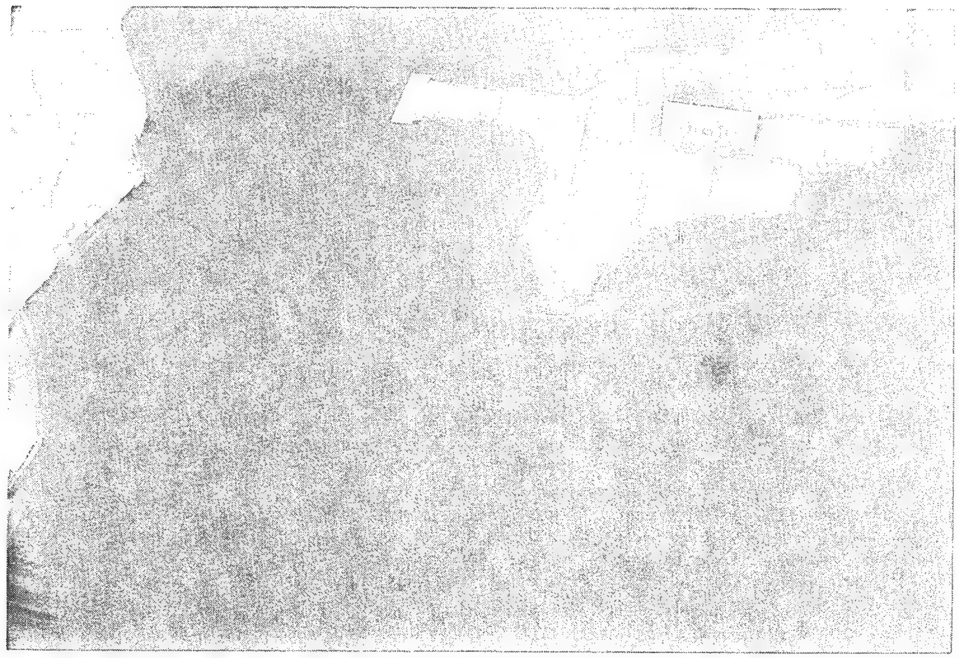
Photo 141. Progression of sediment tracer movement at Camp Ellis Beach for pre-breakwater conditions (27-32 hr)



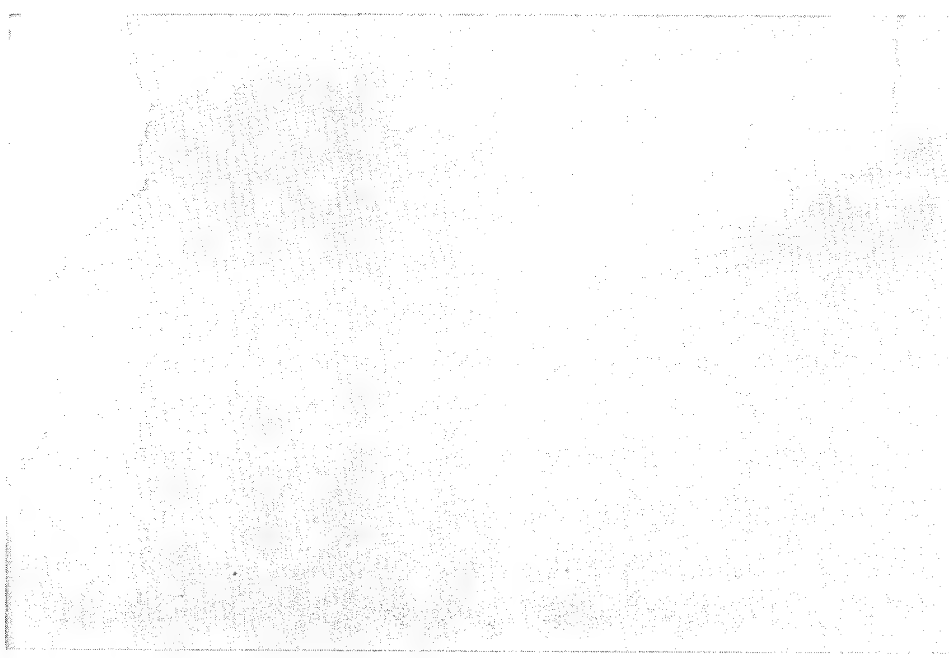
5 hr

10 hr

Photo 142. Progression of sediment tracer movement at the river entrance and southern portion of the beach for pre-breakwater conditions (5-10 hr)

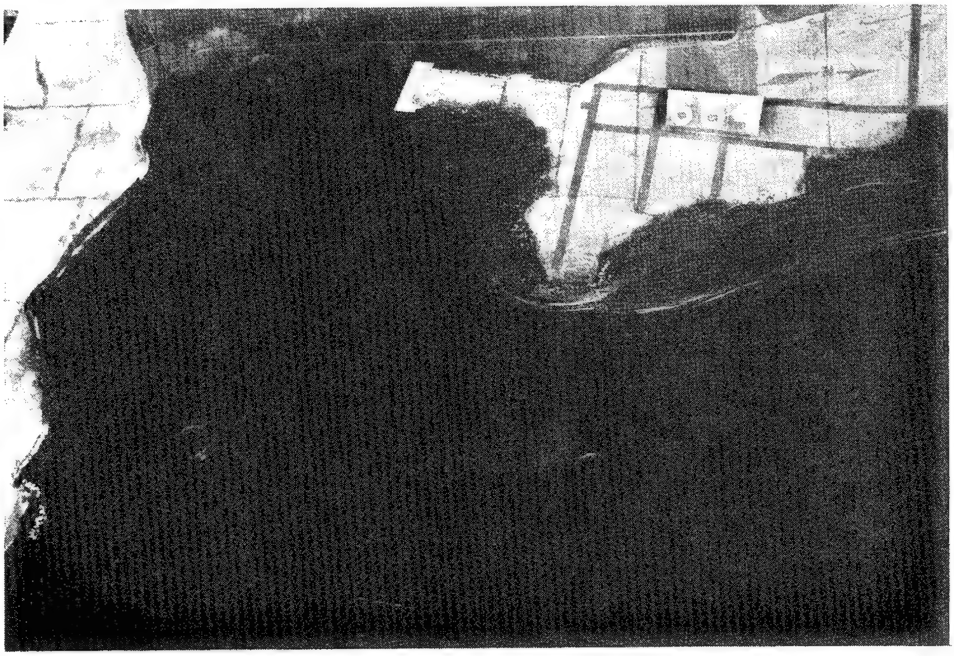


13 hr

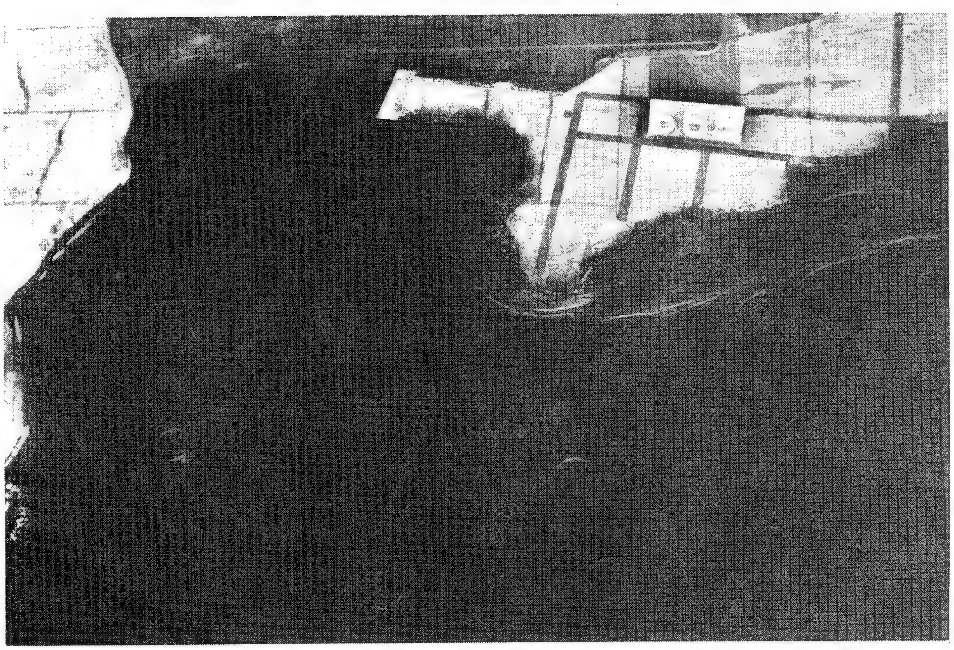


16 hr

Photo 143. Progression of sediment tracer movement at the river entrance and southern portion of the beach for pre-breakwater conditions (13-16 hr)

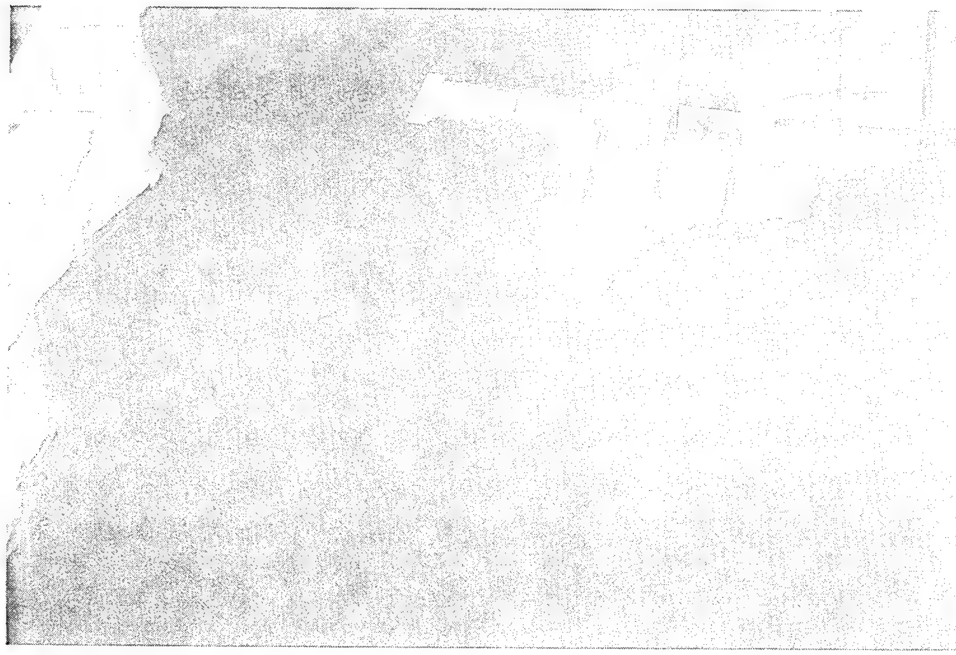


19 hr

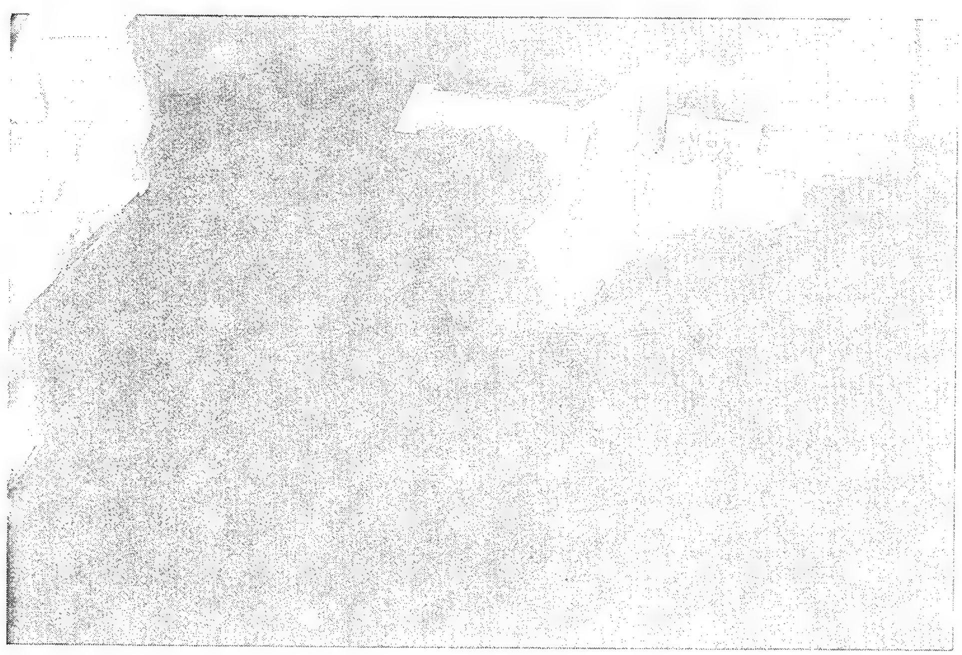


22 hr

Photo 144. Progression of sediment tracer movement at the river entrance and southern portion of the beach for pre-breakwater conditions (19-22 hr)

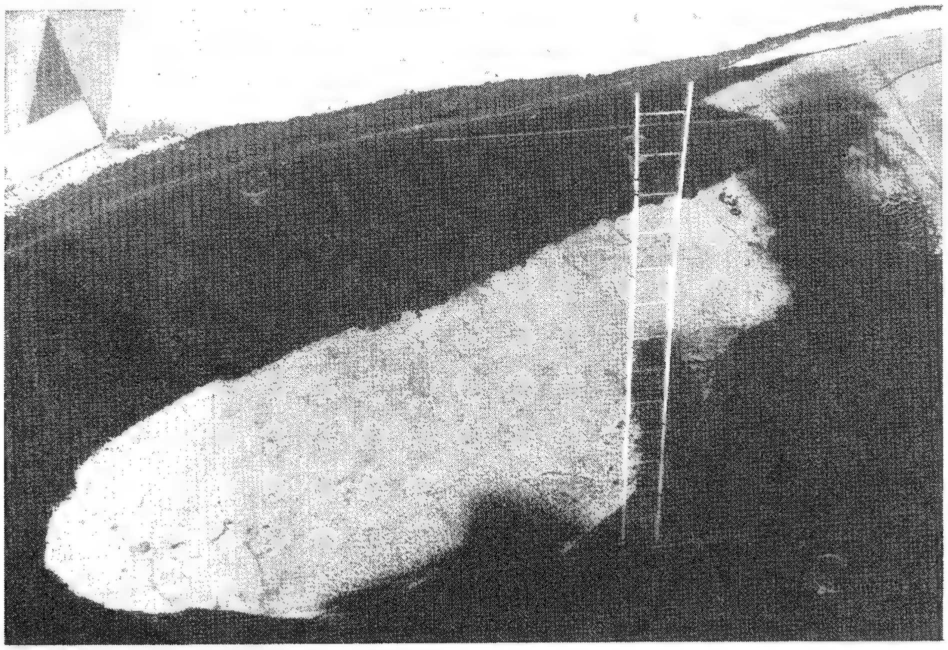


27 hr

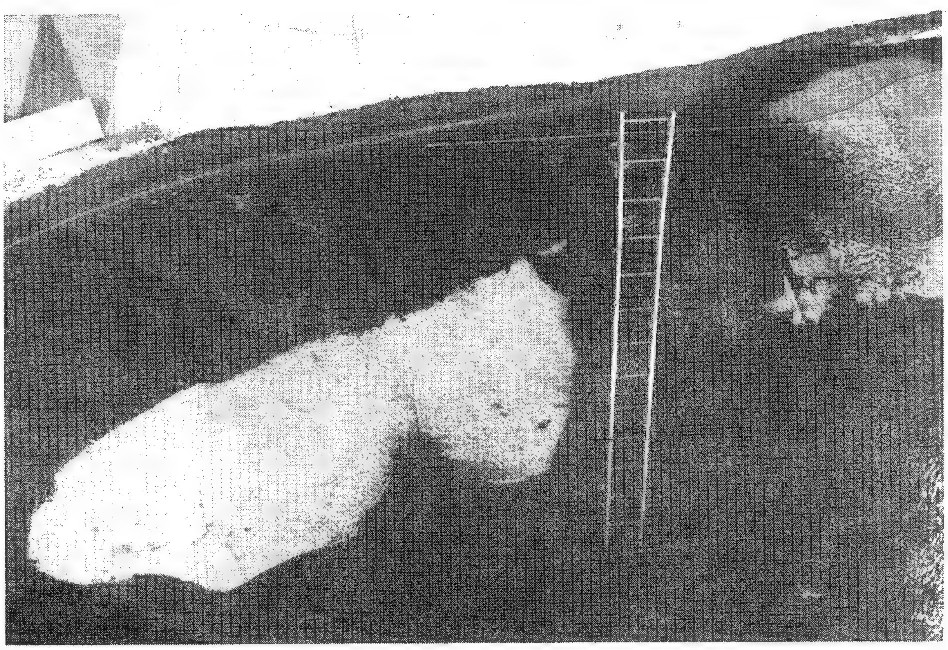


32 hr

Photo 145. Progression of sediment tracer movement at the river entrance and southern portion of the beach for pre-breakwater conditions (27-32 hr)

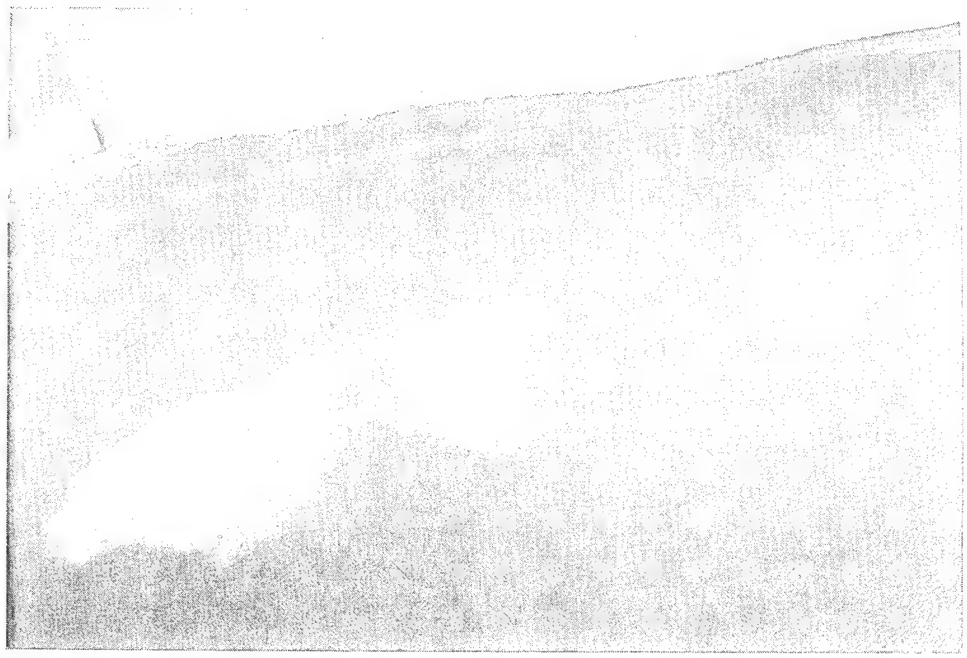


5 hr



10 hr

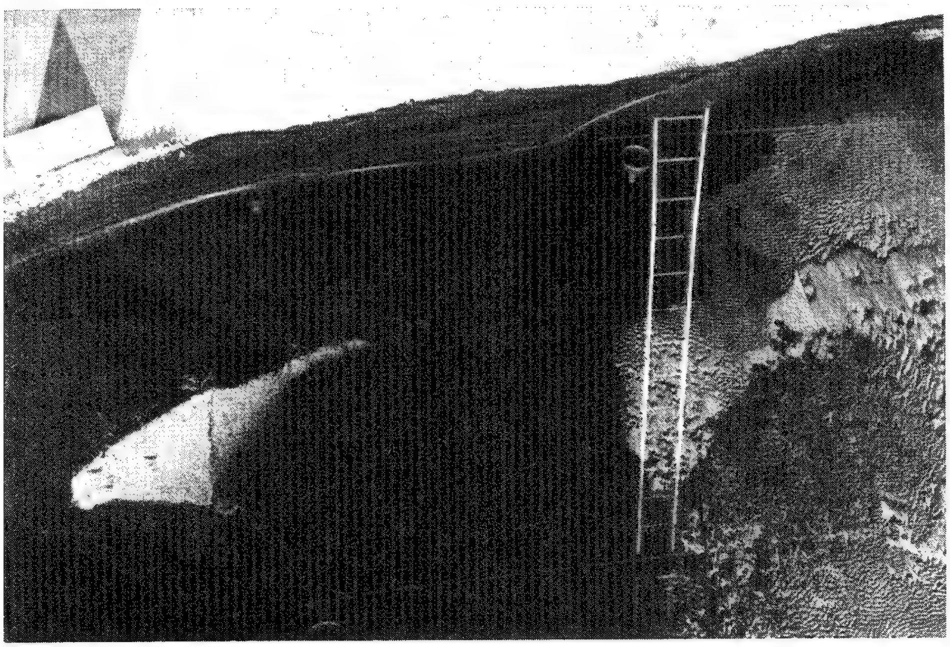
Photo 146. Progression of sediment tracer movement along the northern portion of the beach for pre-breakwater conditions (5-10 hr)



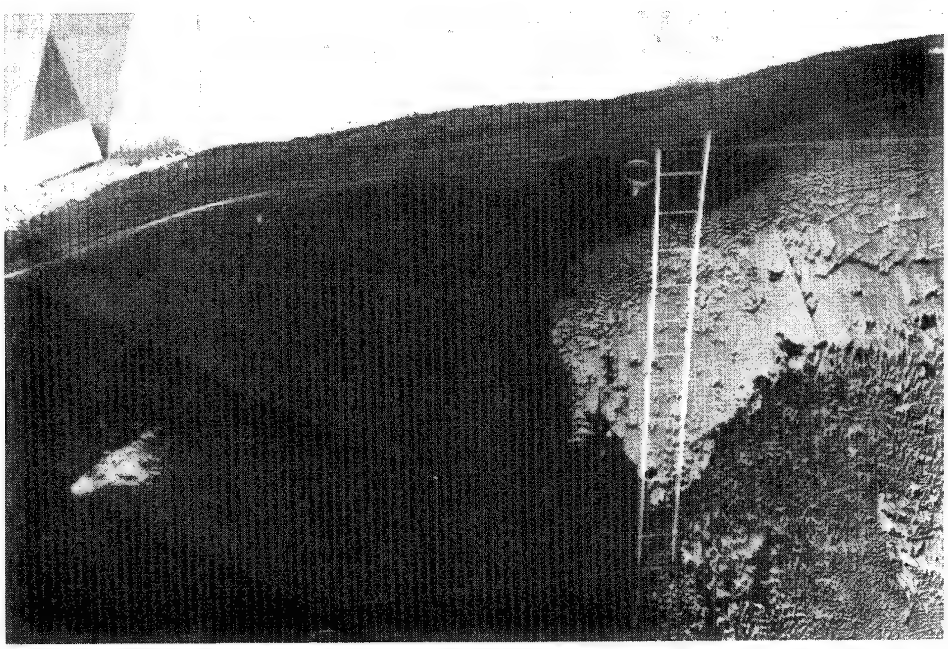
13 hr

16 hr

Photo 147. Progression of sediment tracer movement along the northern portion of the beach for pre-breakwater conditions (13-16 hr)

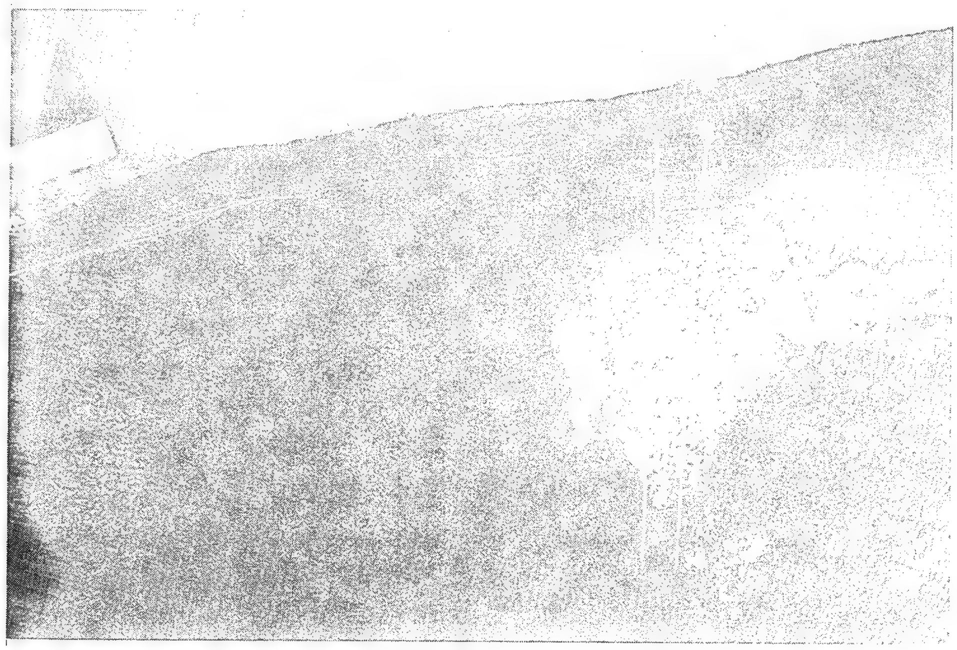


19 hr



22 hr

Photo 148. Progression of sediment tracer movement along the northern portion of the beach for pre-breakwater conditions (19-22 hr)



27 hr

32 hr

Photo 149. Progression of sediment tracer movement along the northern portion of the beach for pre-breakwater conditions (27-32 hr)

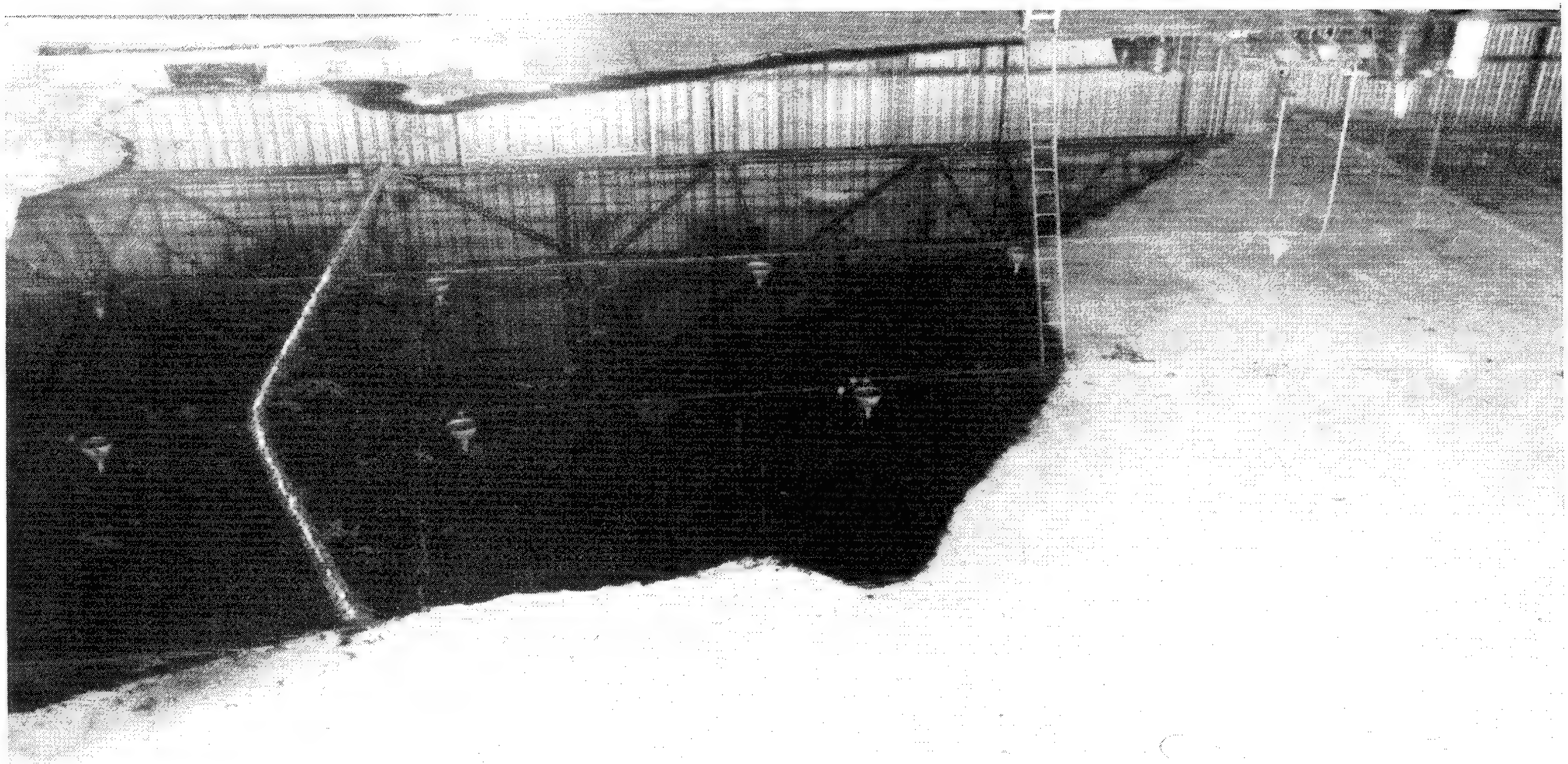
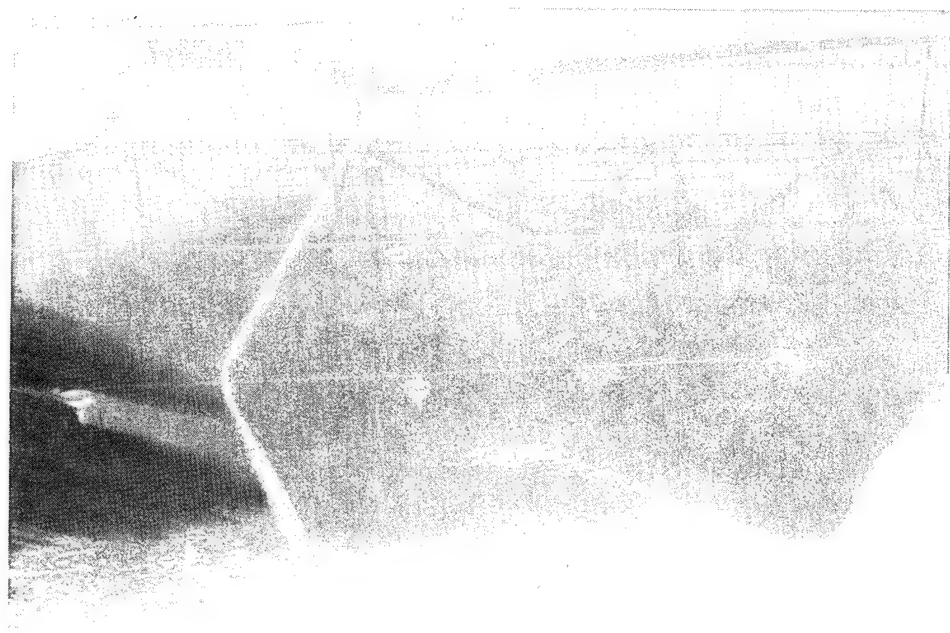
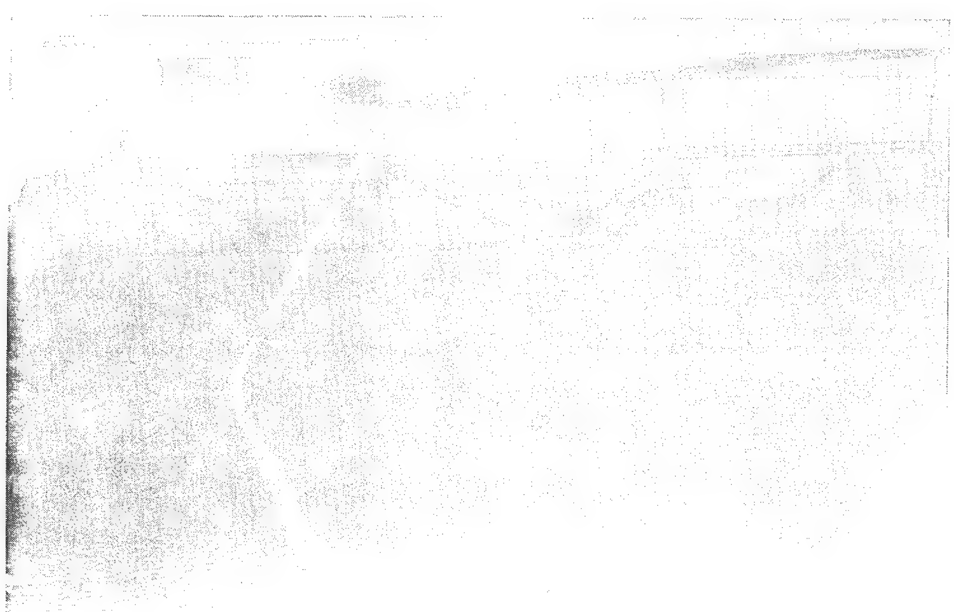


Photo 150. Overall view of original breakwater conditions prior to model testing

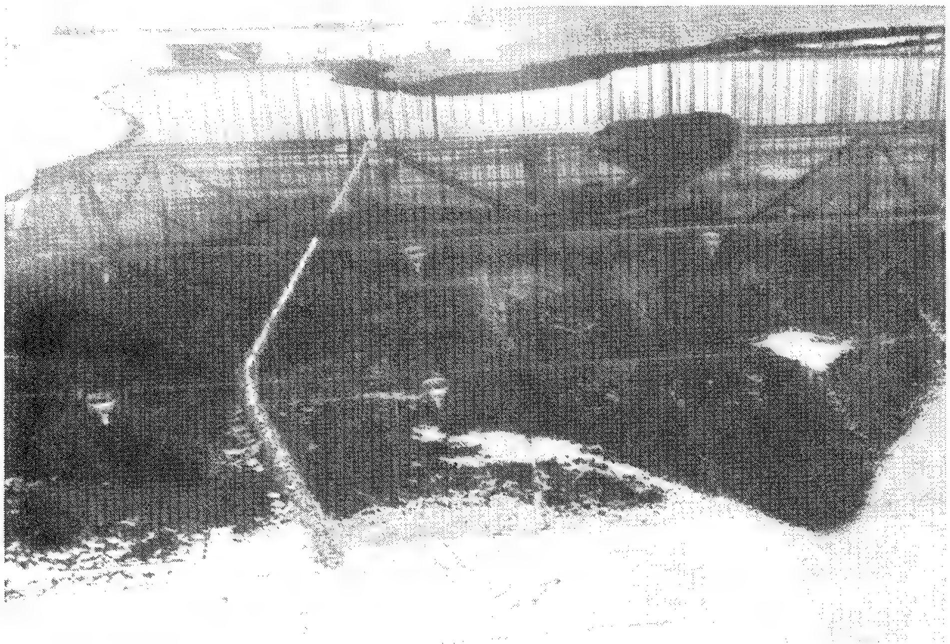


5 hr

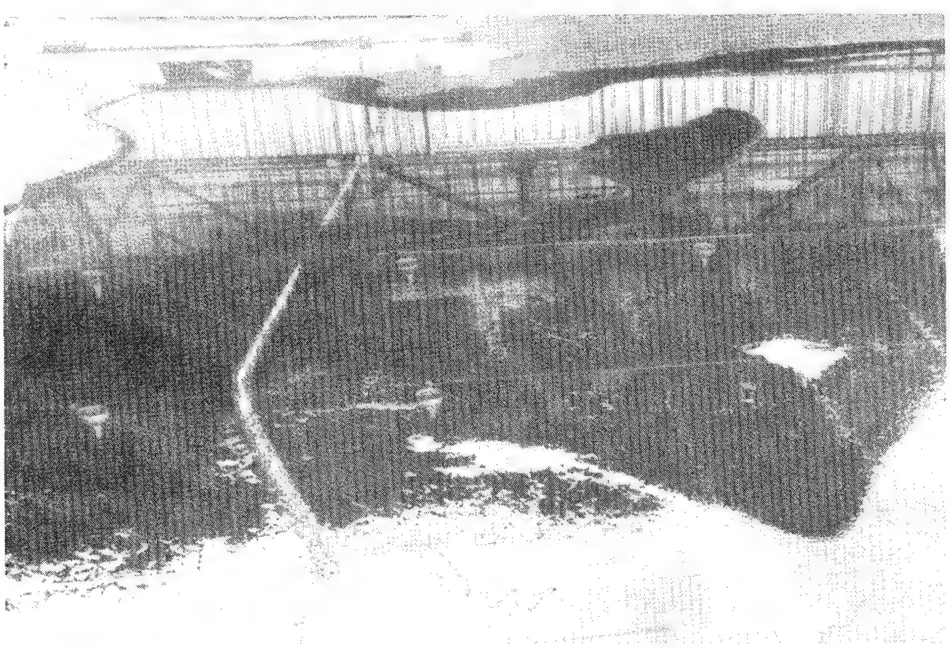


10 hr

Photo 151. Progression of sediment tracer movement at Camp Ellis Beach for original breakwater conditions (5-10 hr)



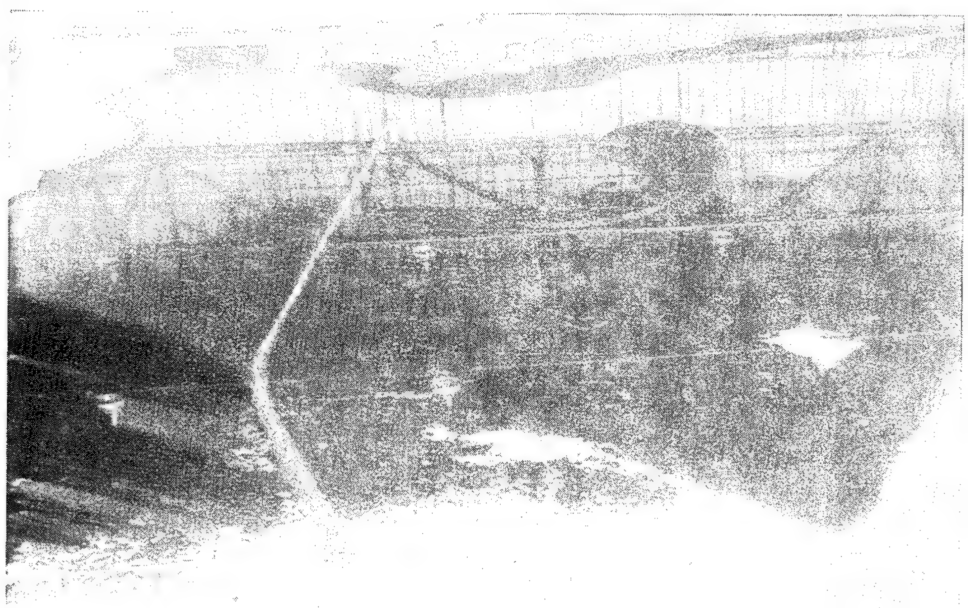
13 hr



16 hr

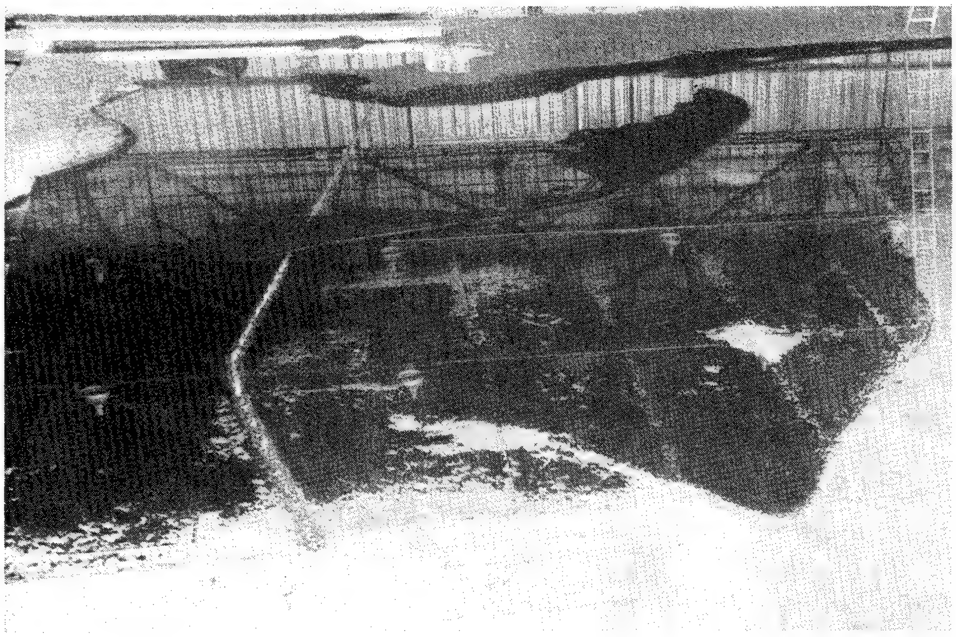
Photo 152. Progression of sediment tracer movement at Camp Ellis Beach for original breakwater conditions (13-16 hr)

19 hr

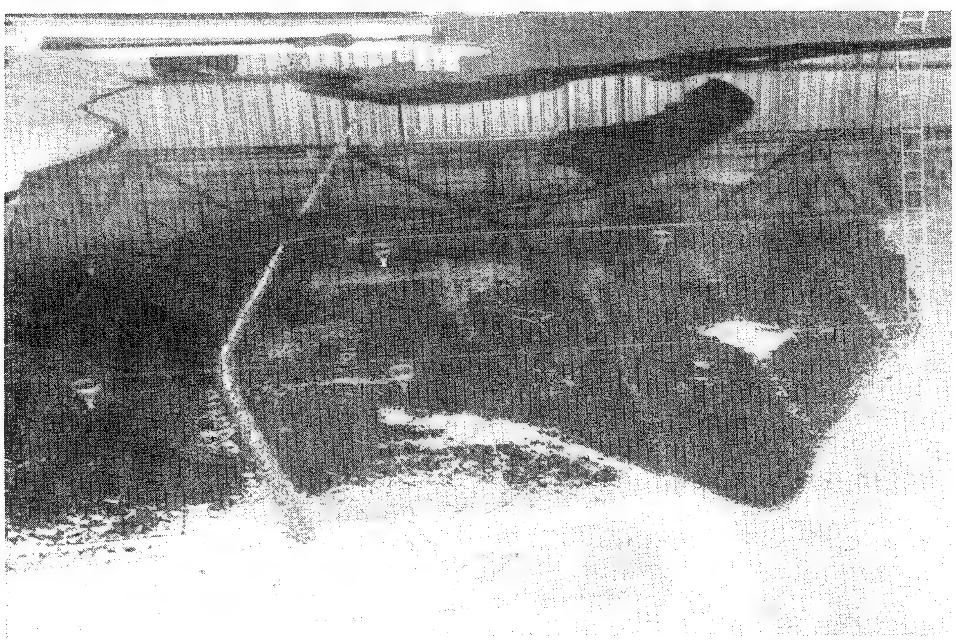


22 hr

Photo 153. Progression of sediment tracer movement at Camp Ellis Beach for original breakwater conditions (19-22 hr)

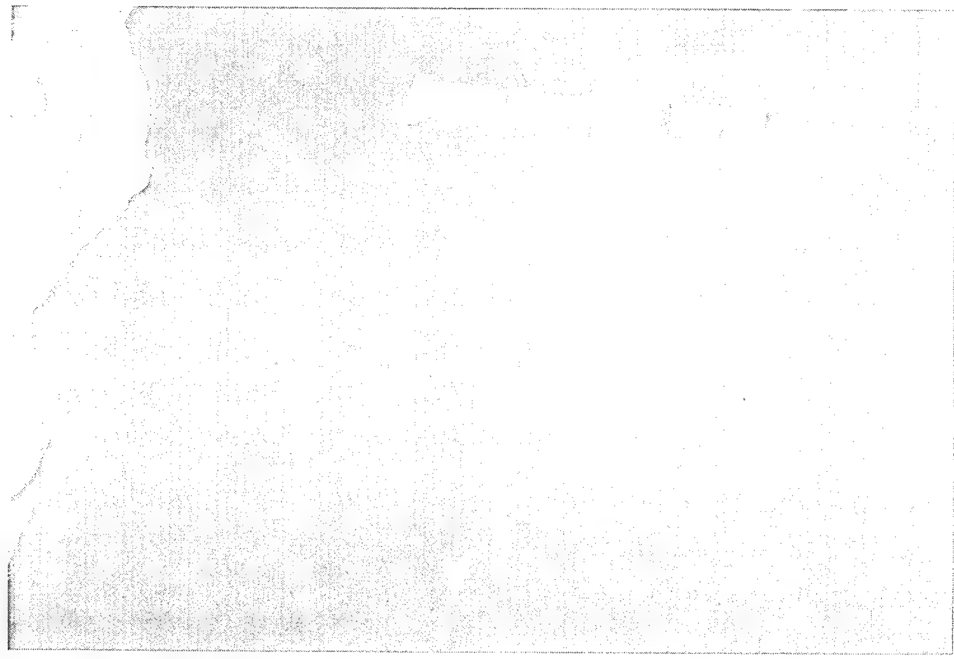


27 hr

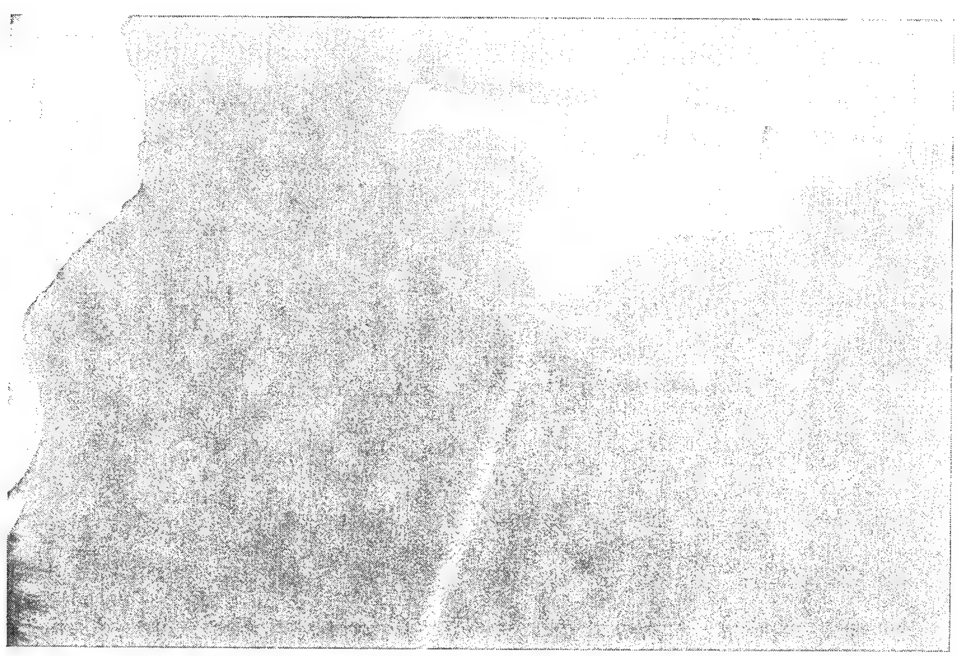


32 hr

Photo 154. Progression of sediment tracer movement at Camp Ellis Beach for original breakwater conditions (27-32 hr)

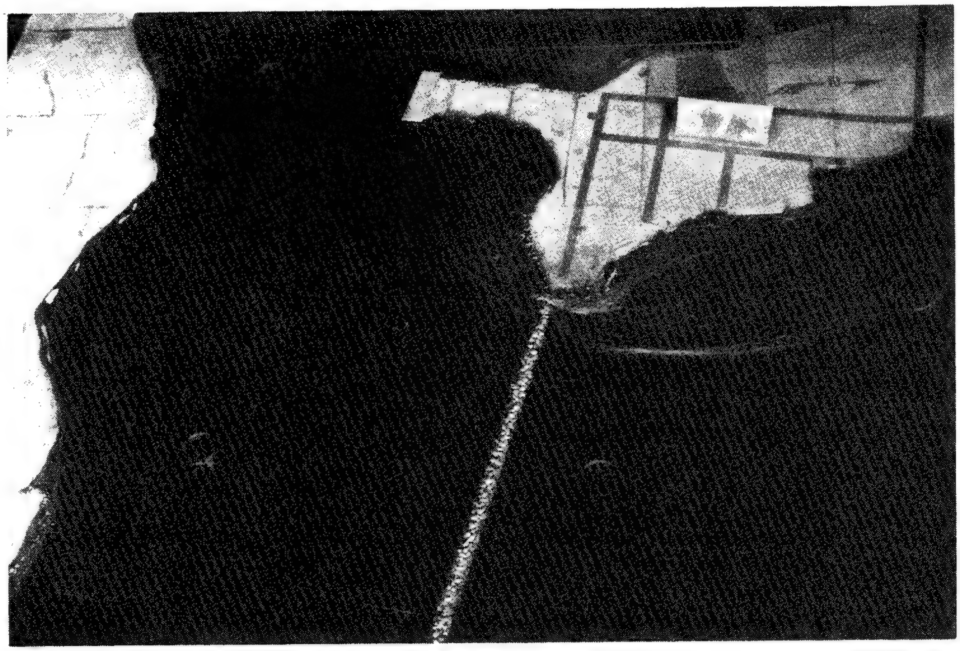


5 hr

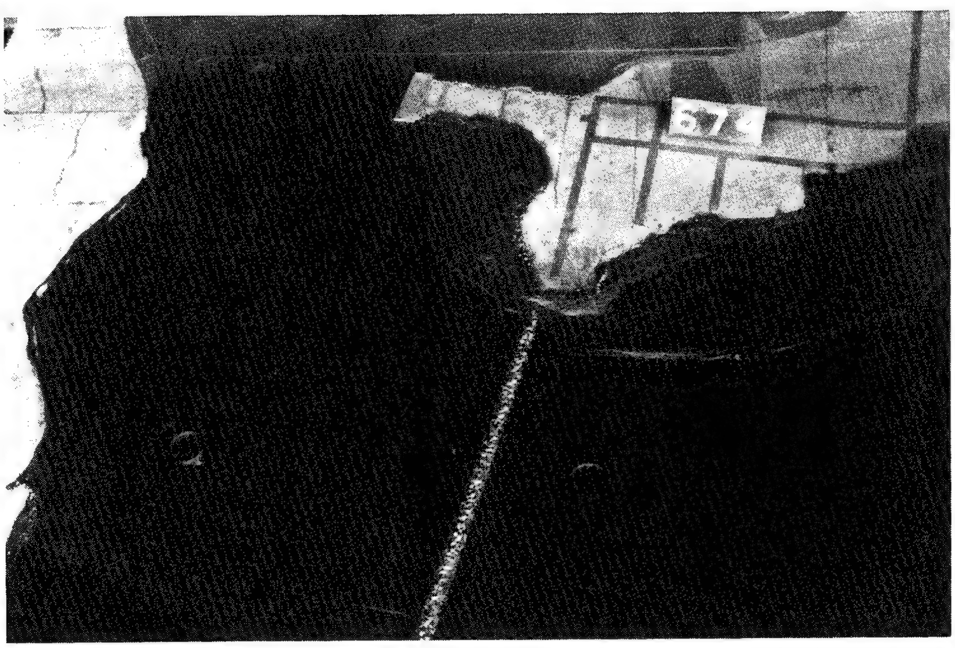


10 hr

Photo 155. Progression of sediment tracer movement at the river entrance and southern portion of the beach for original breakwater conditions (5-10 hr)

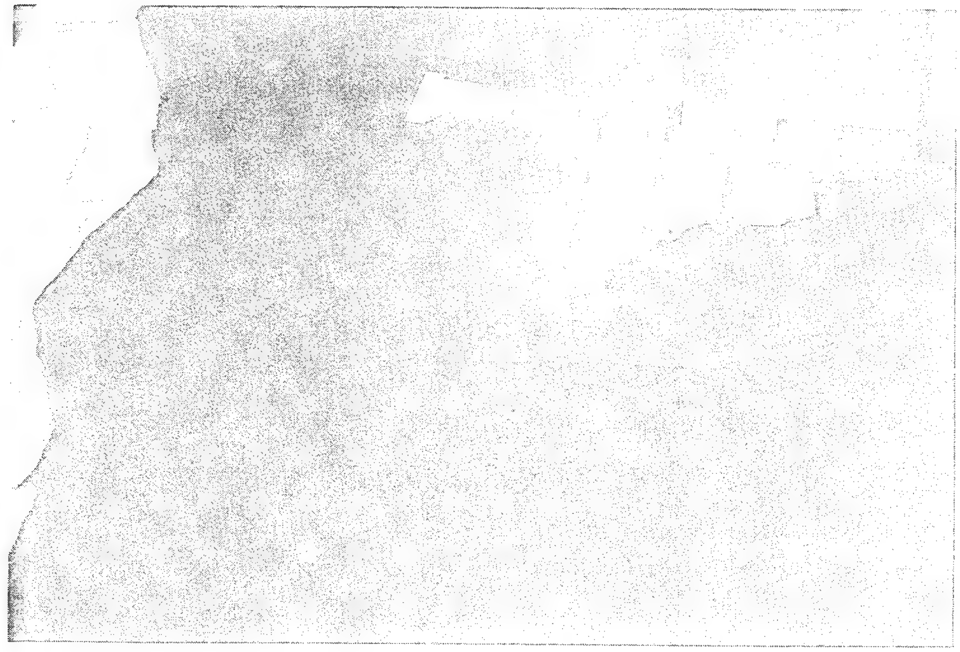


13 hr

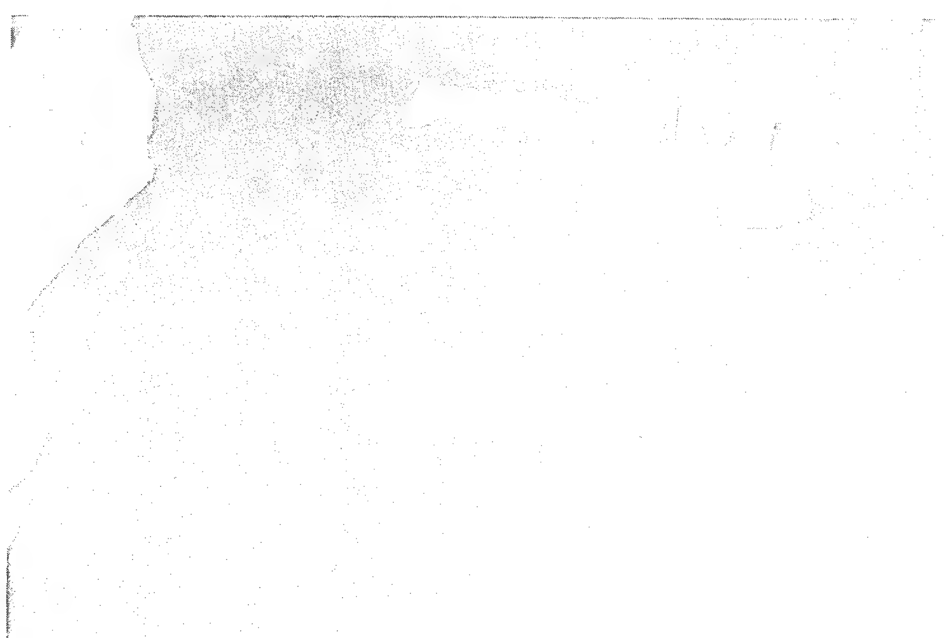


16 hr

Photo 156. Progression of sediment tracer movement at the river entrance and southern portion of the beach for original breakwater conditions (13-16 hr)

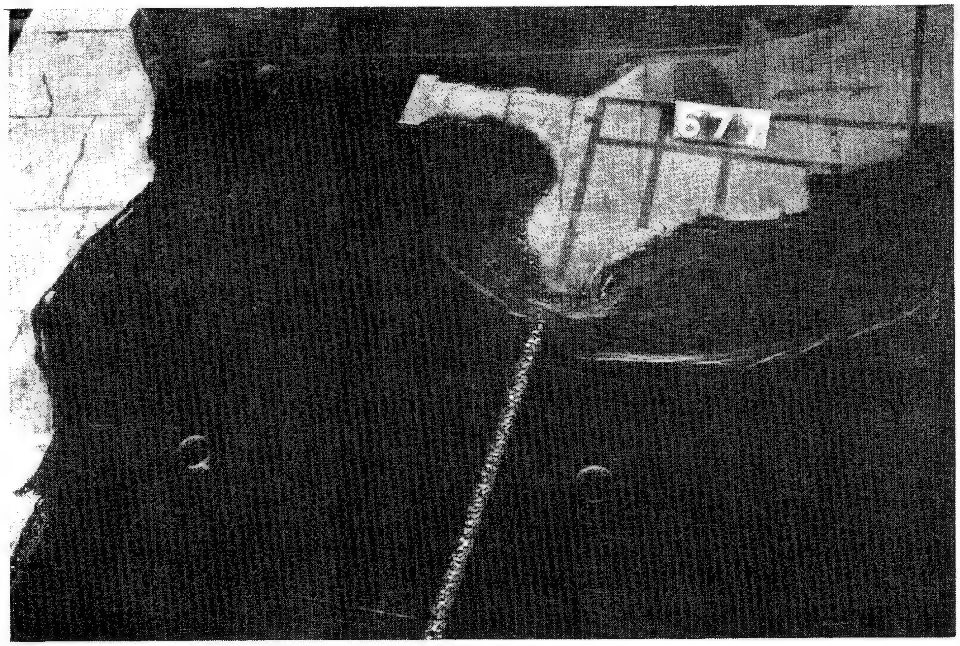


19 hr

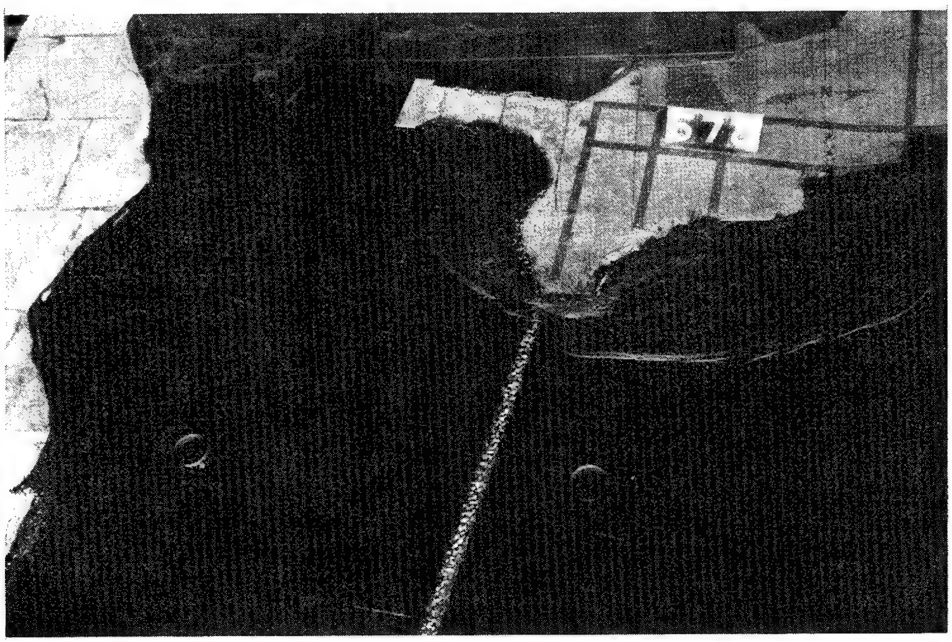


22 hr

Photo 157. Progression of sediment tracer movement at the river entrance and southern portion of the beach for original breakwater conditions (19-22 hr)

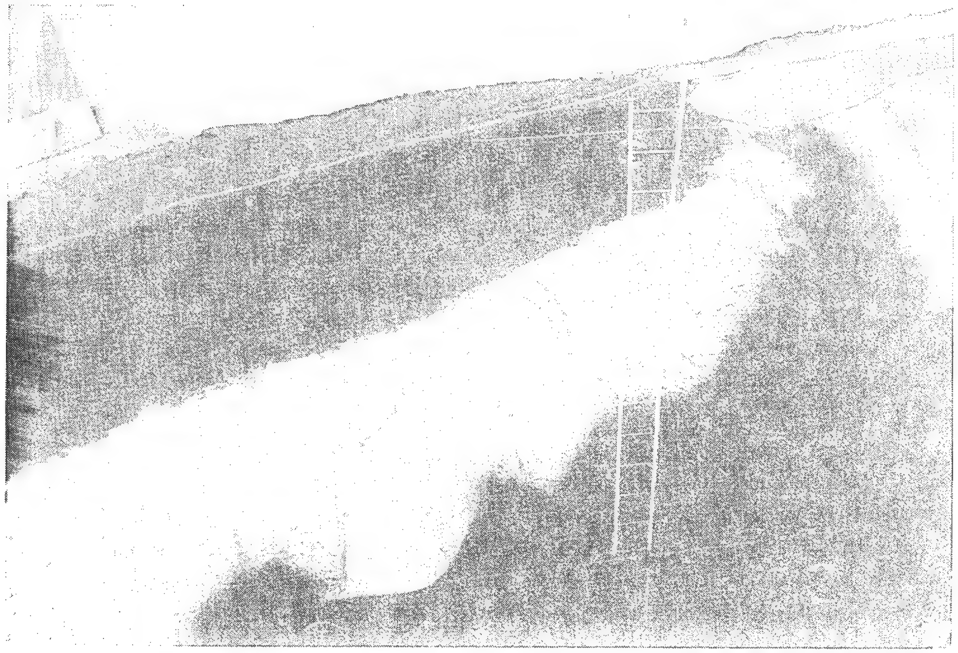


27 hr



32 hr

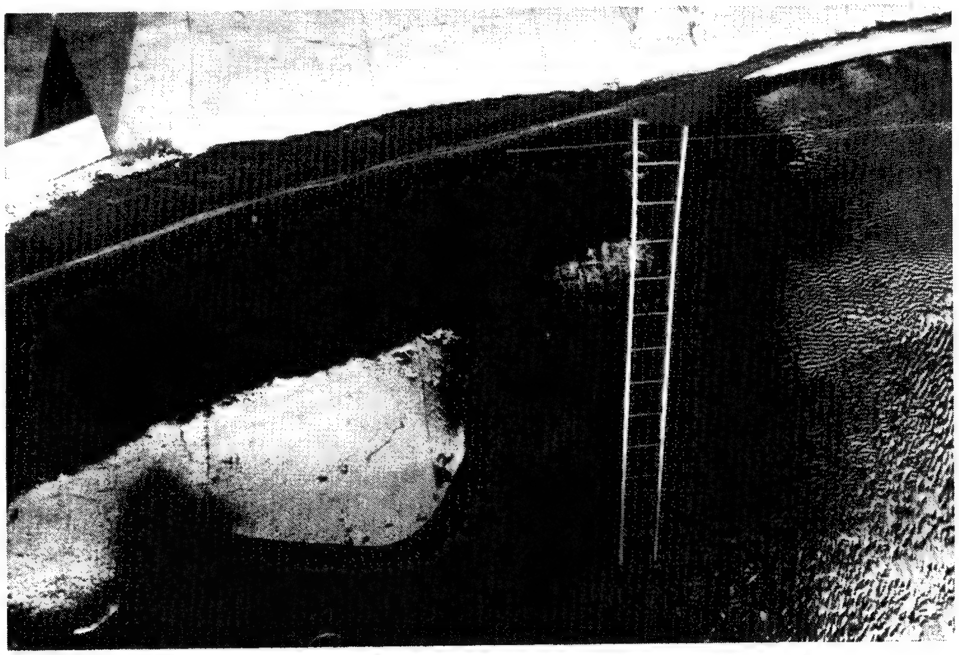
Photo 158. Progression of sediment tracer movement at the river entrance and southern portion of the beach for original breakwater conditions (27-32 hr)



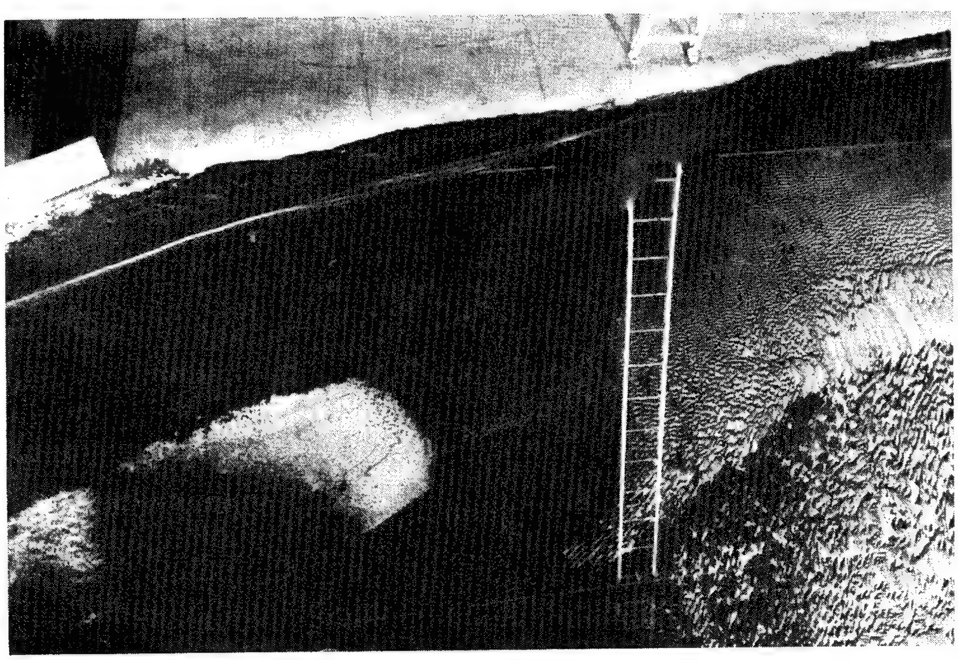
5 hr

10 hr

Photo 159. Progression of sediment tracer movement along the northern portion of the beach for original breakwater conditions (5-10 hr)

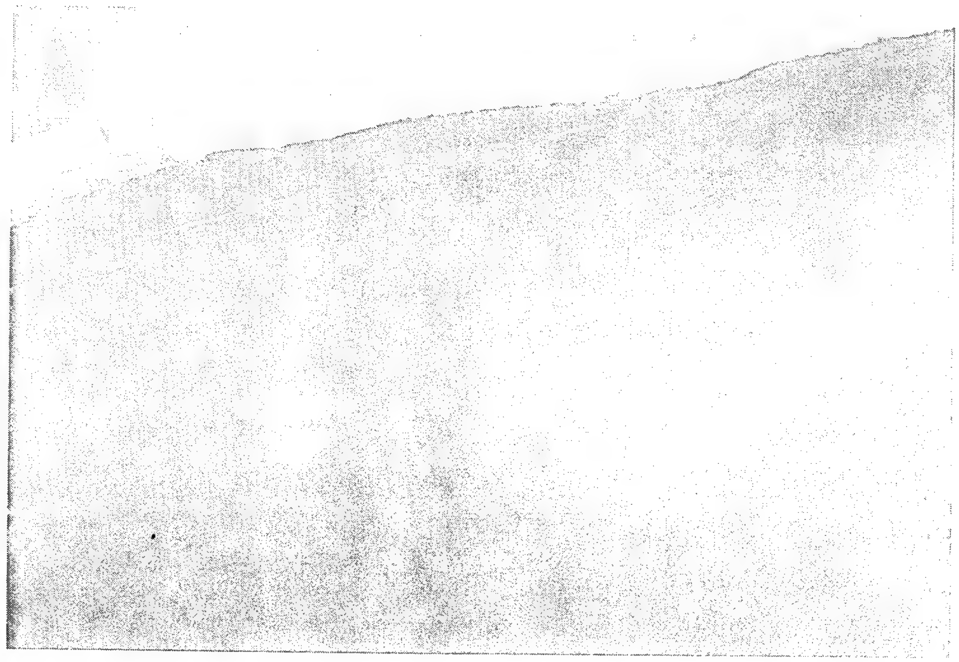


13 hr

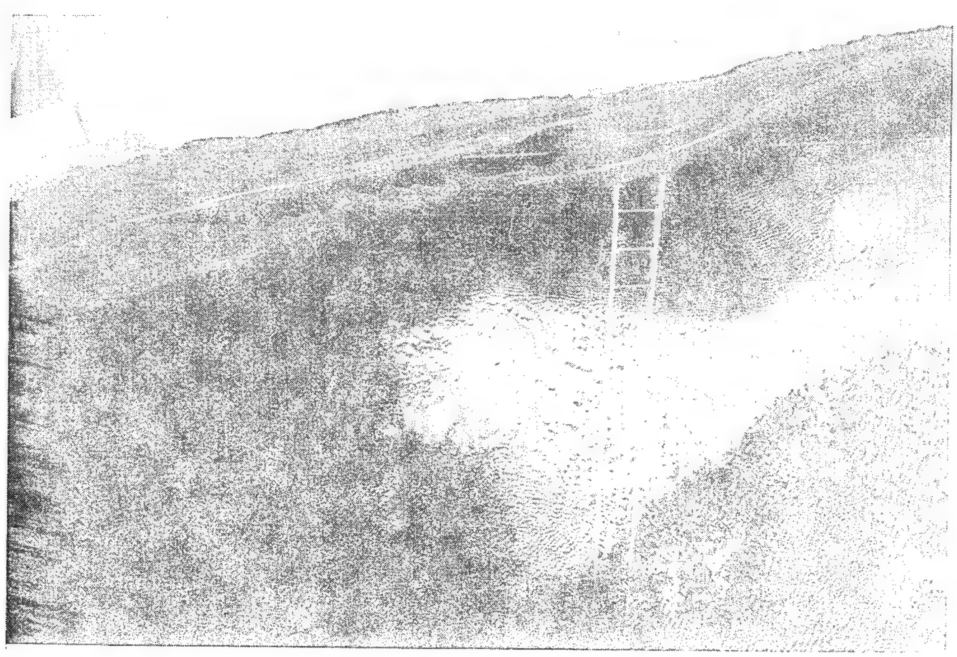


16 hr

Photo 160. Progression of sediment tracer movement along the northern portion of the beach for original breakwater conditions (13-16 hr)

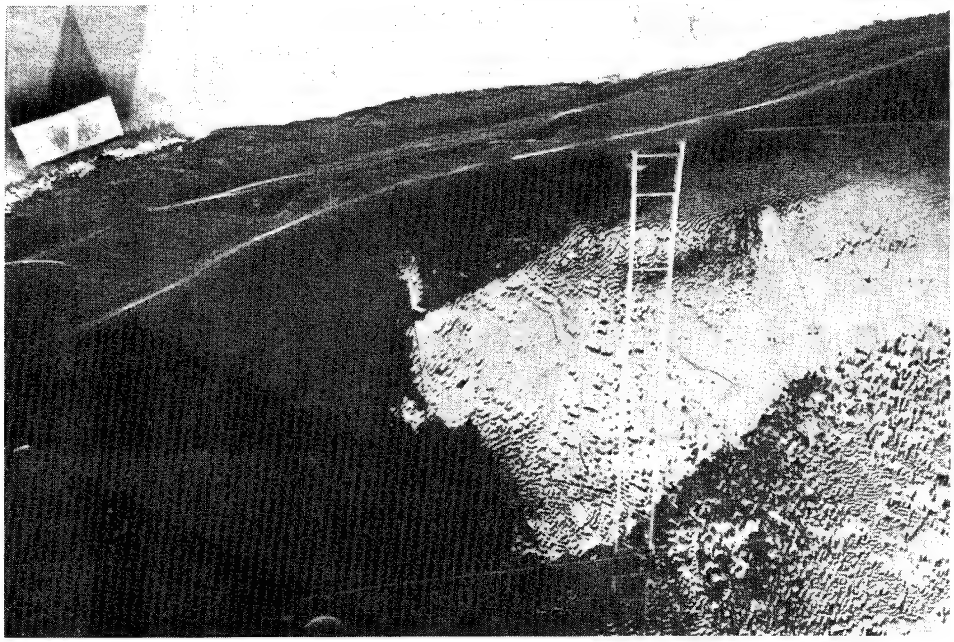


19 hr

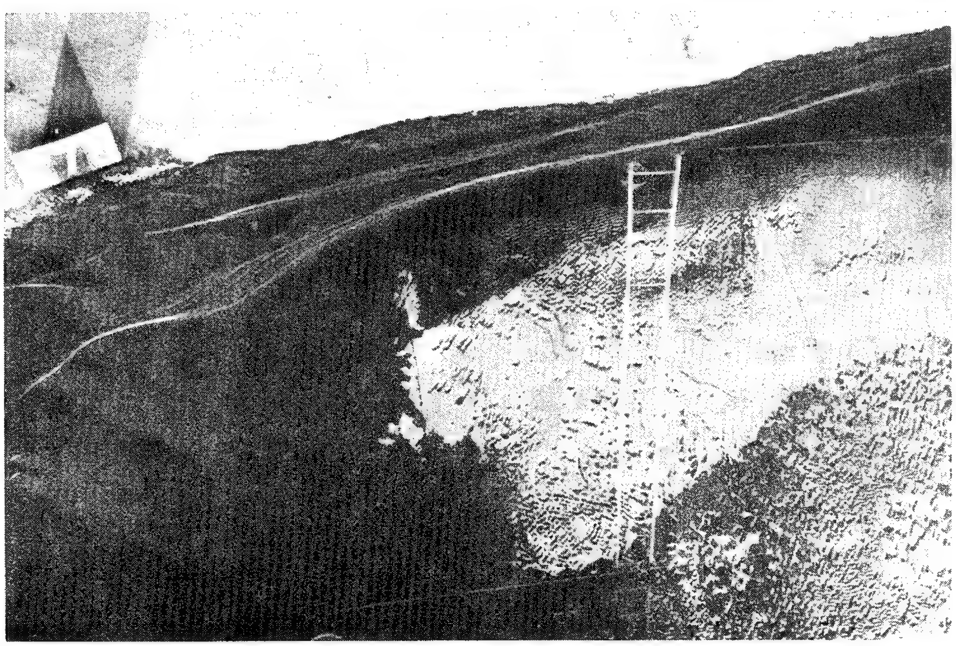


22 hr

Photo 161. Progression of sediment tracer movement along the northern portion of the beach for original breakwater conditions (19-22 hr)



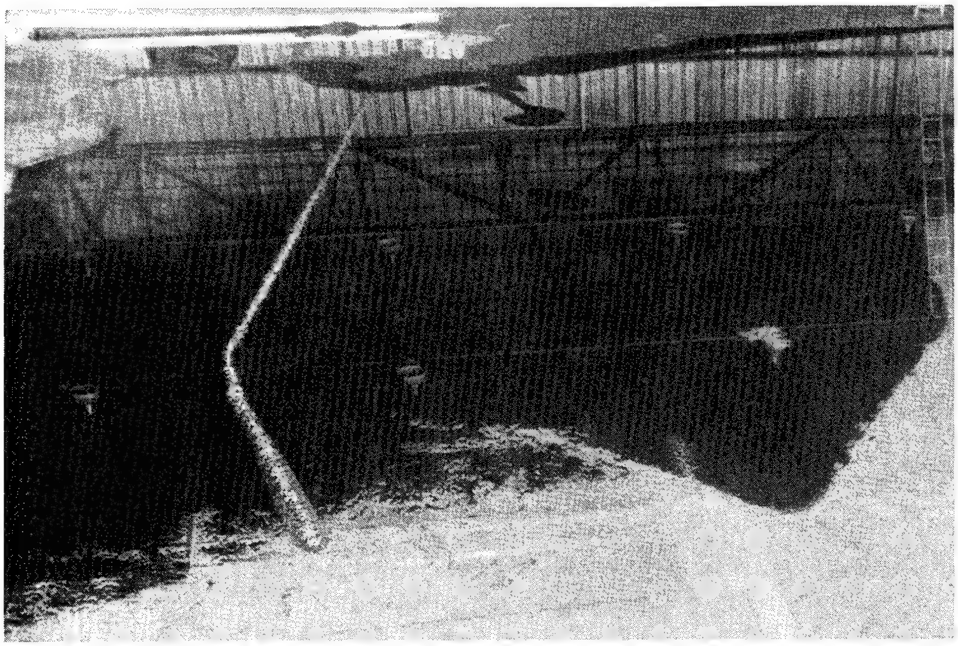
27 hr



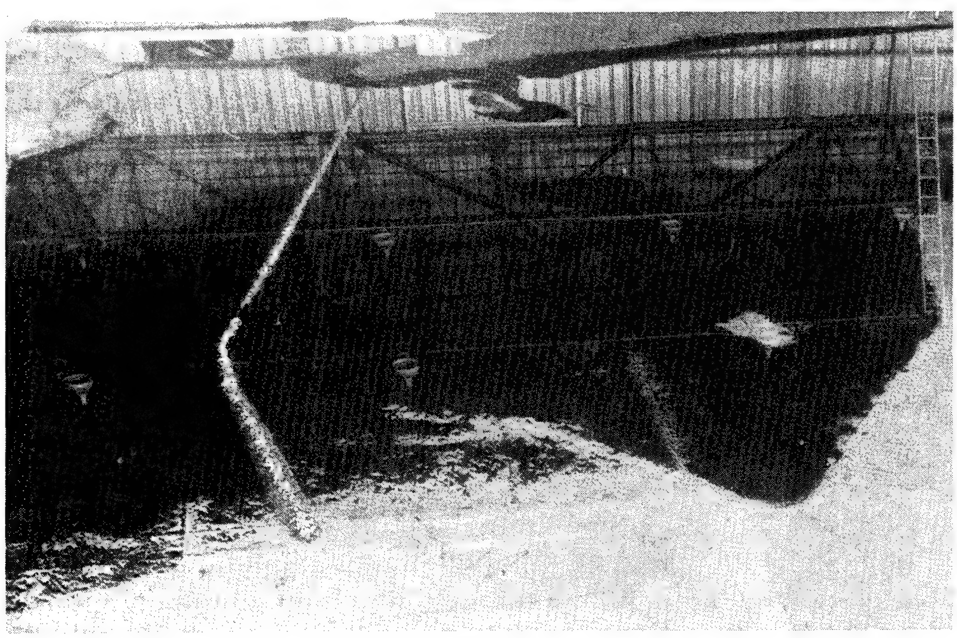
32 hr

Photo 162. Progression of sediment tracer movement along the northern portion of the beach for original breakwater conditions (27-32 hr)

Photo 163. Overall view of raised breakwater conditions prior to model testing

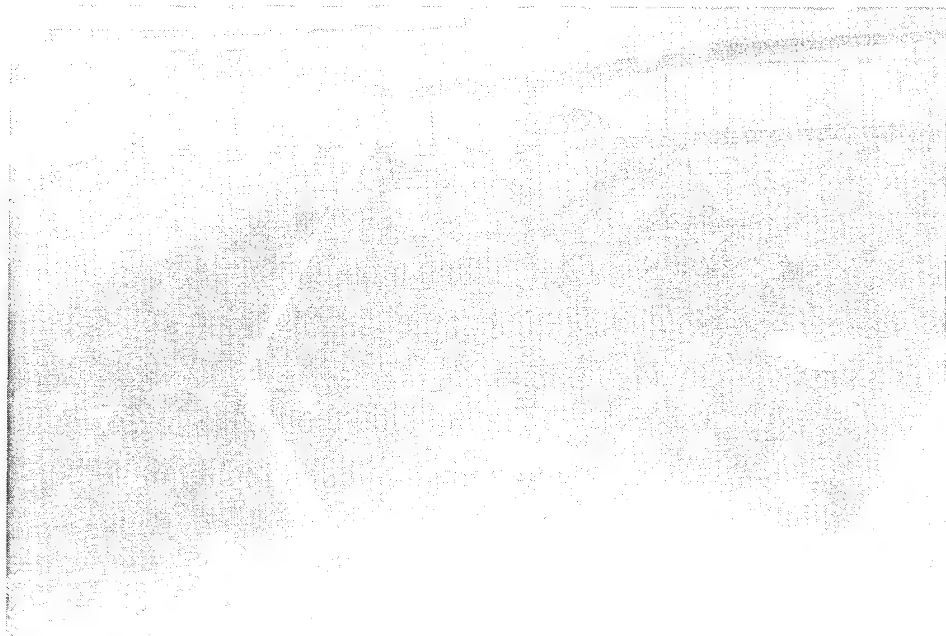


5 hr

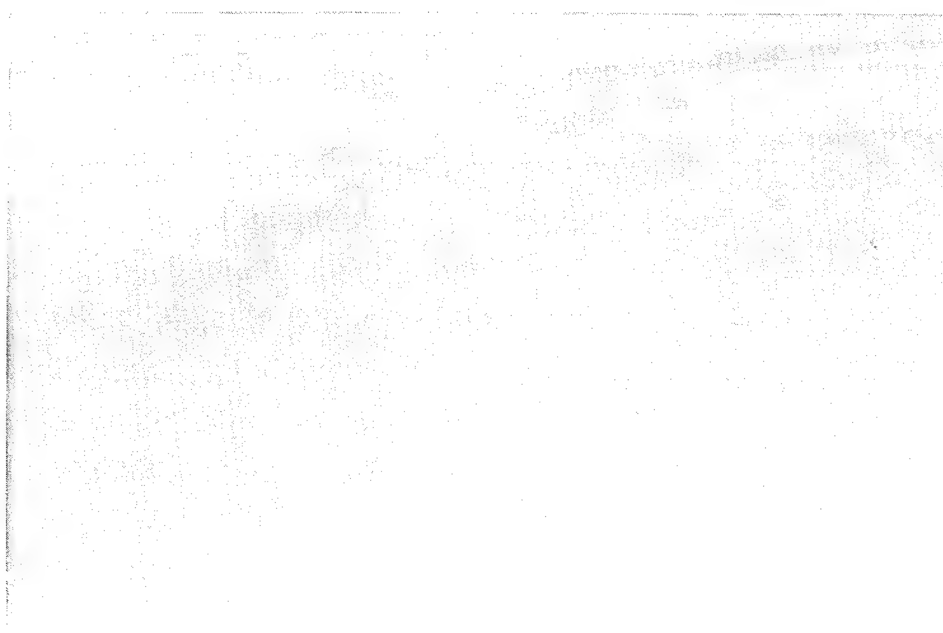


10 hr

Photo 164. Progression of sediment tracer movement at Camp Ellis Beach for raised breakwater conditions (5-10 hr)

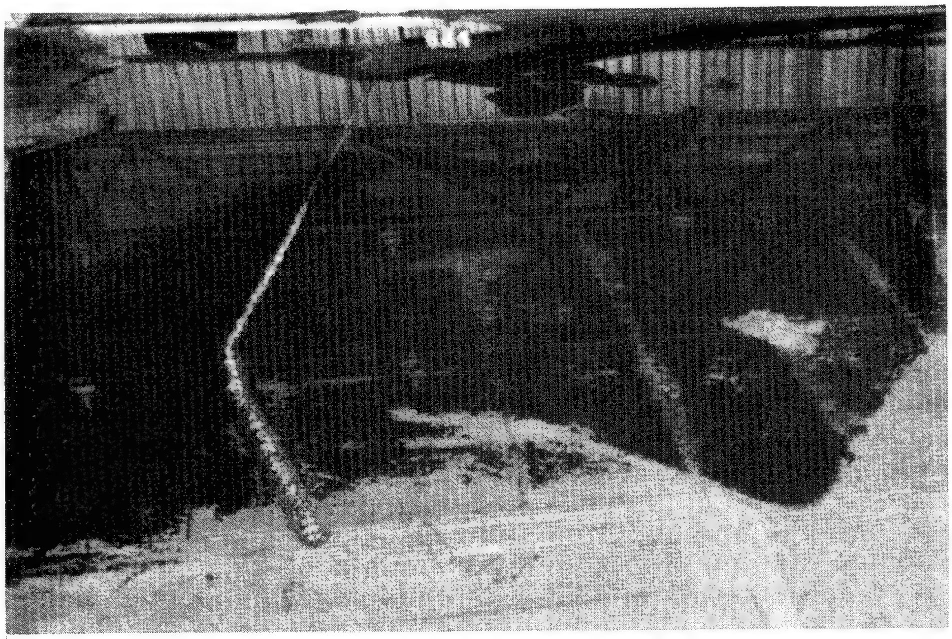


13 hr

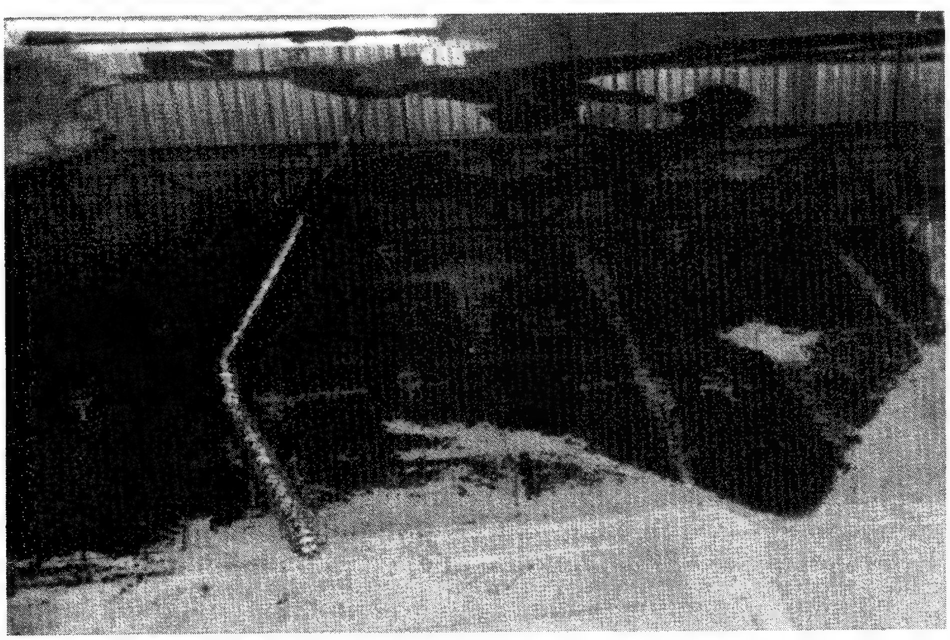


16 hr

Photo 165. Progression of sediment tracer movement at Camp Ellis Beach for raised breakwater conditions (13-16 hr)



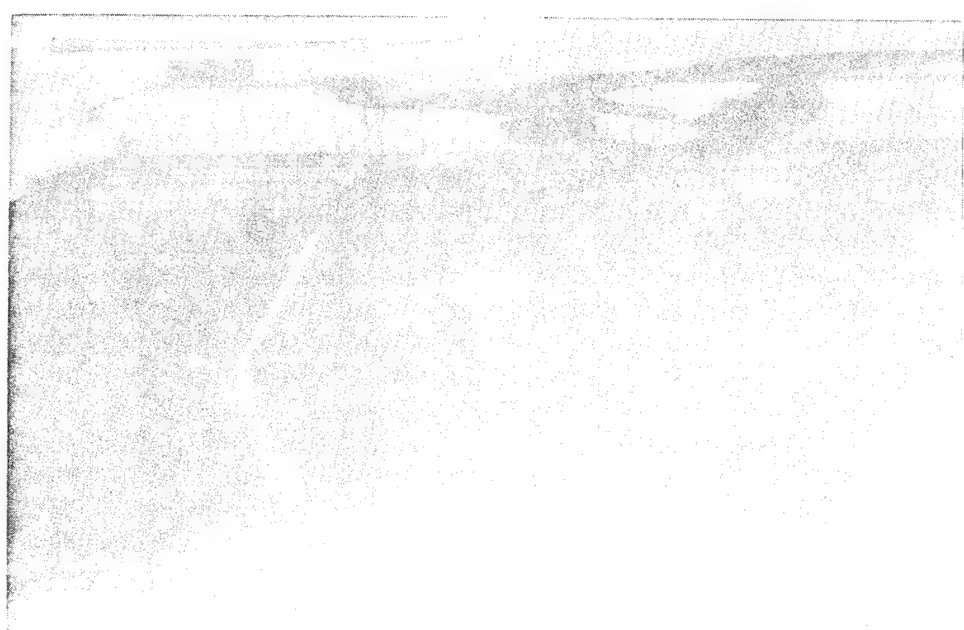
19 hr



22 hr

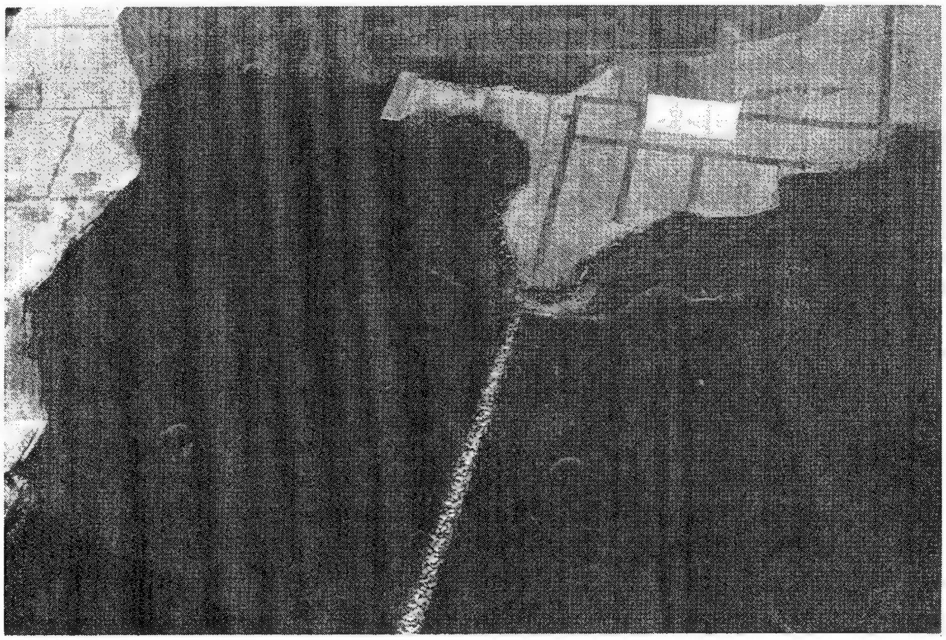
Photo 166. Progression of sediment tracer movement at Camp Ellis Beach for raised breakwater conditions (19-22 hr)

27 hr

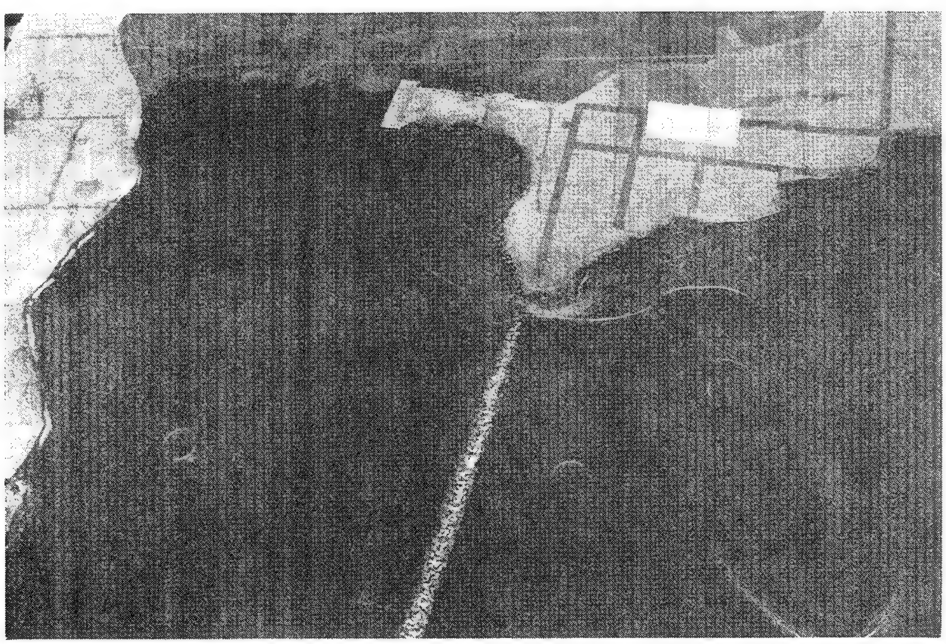


32 hr

Photo 167. Progression of sediment tracer movement at Camp Ellis Beach for raised breakwater conditions (27-32 hr)

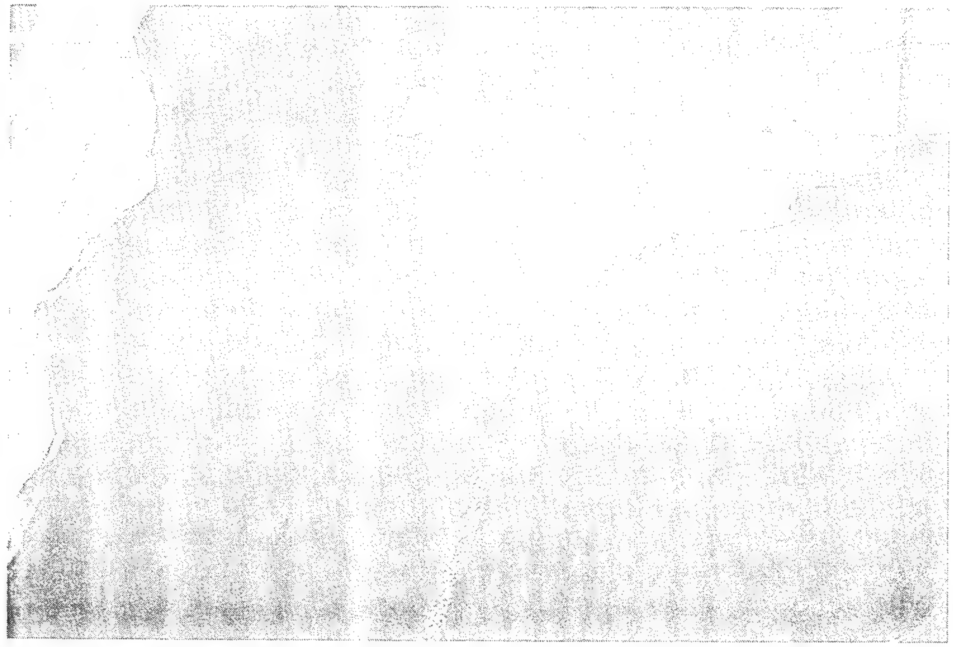


5 hr



10 hr

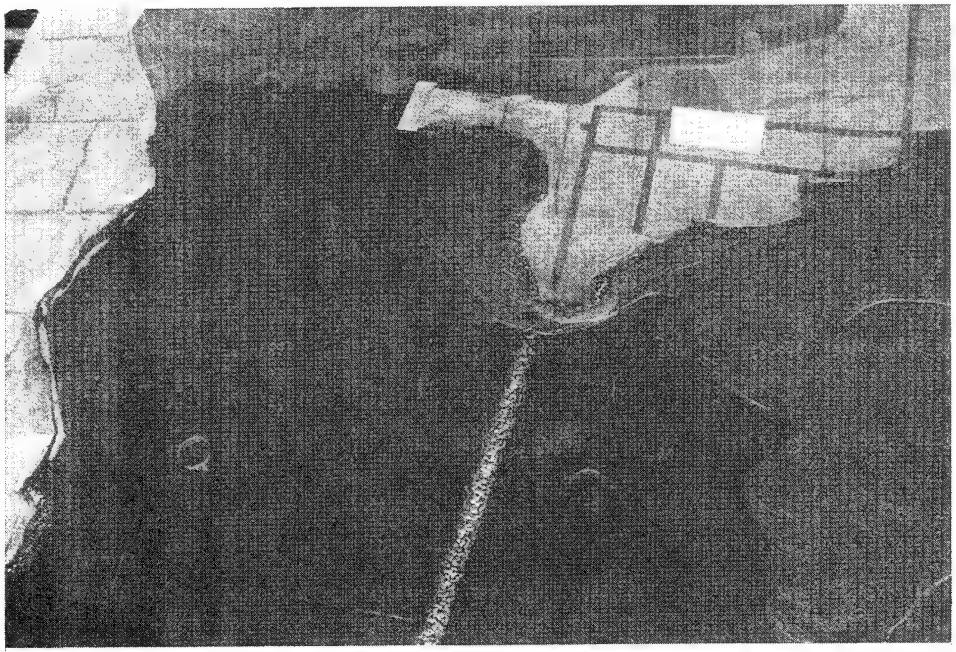
Photo 168. Progression of sediment tracer movement at the river entrance and southern portion of the beach for raised breakwater conditions (5-10 hr)



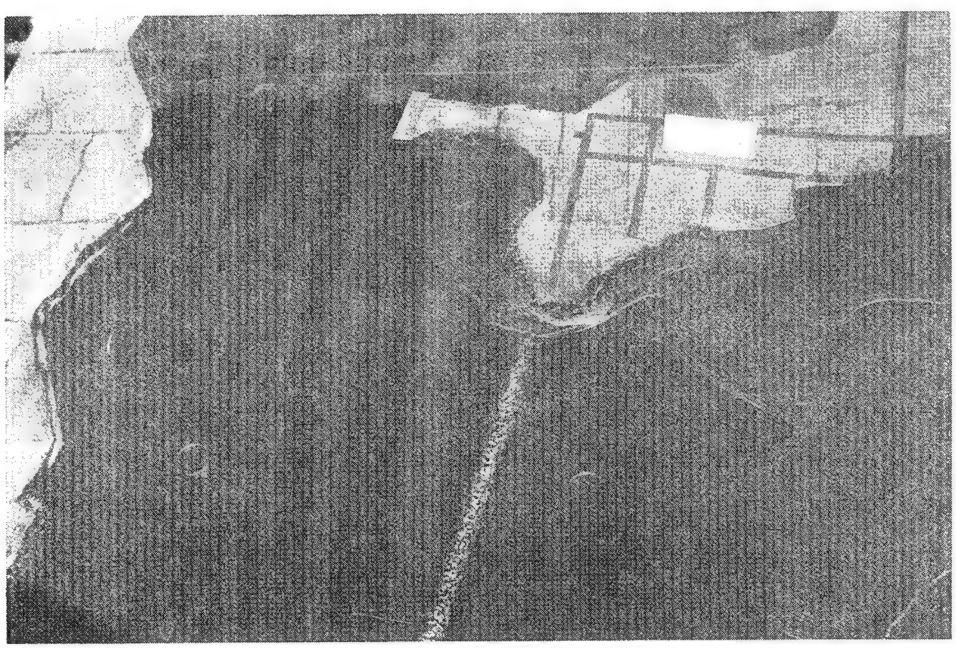
13 hr

16 hr

Photo 169. Progression of sediment tracer movement at the river entrance and southern portion of the beach for raised breakwater conditions (13-16 hr)

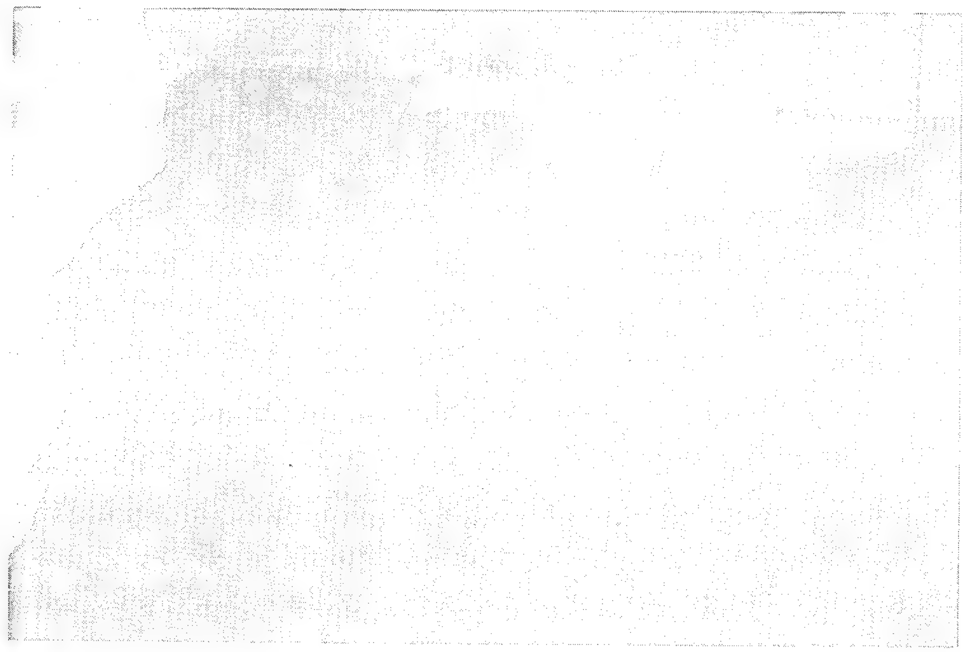


19 hr

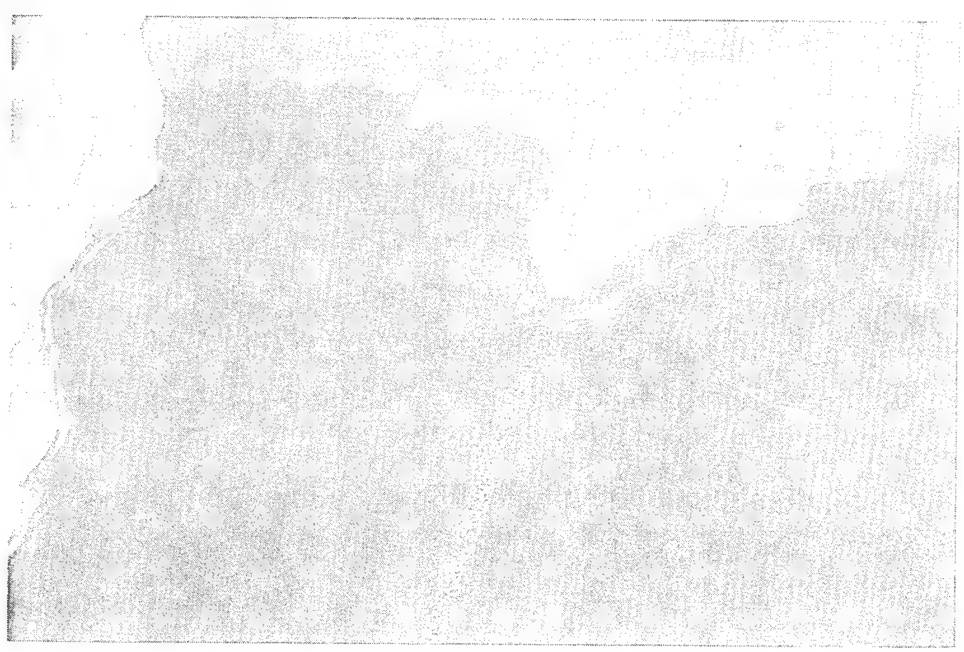


22 hr

Photo 170. Progression of sediment tracer movement at the river entrance and southern portion of the beach for raised breakwater conditions (19-22 hr)

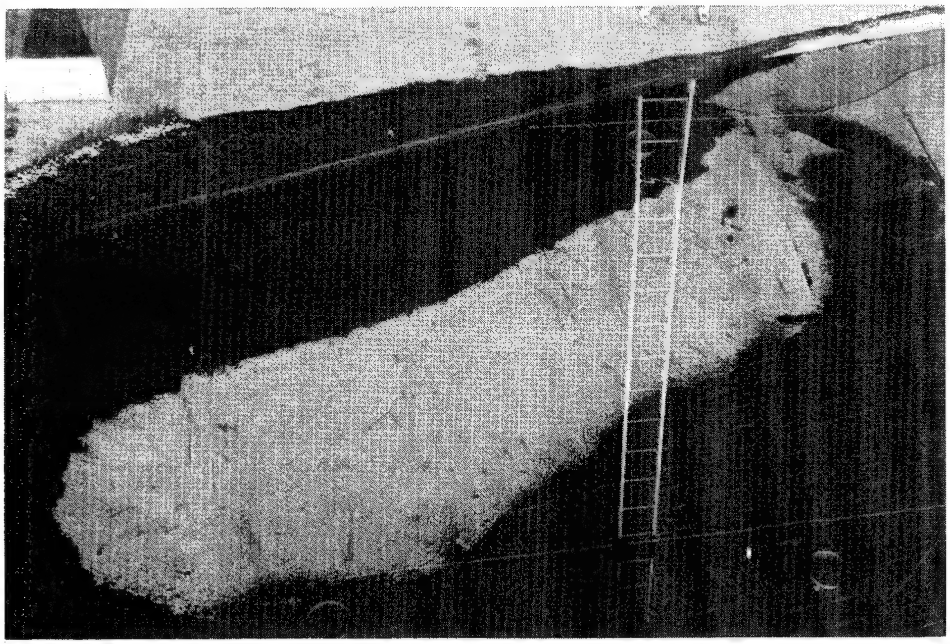


27 hr

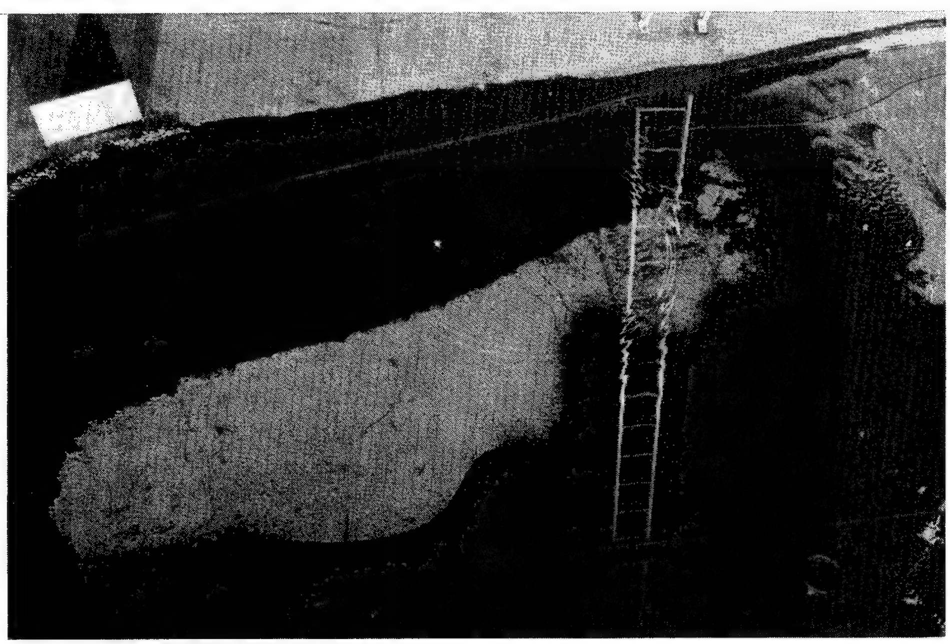


32 hr

Photo 171. Progression of sediment tracer movement at the river entrance and southern portion of the beach for raised breakwater conditions (27-32 hr)

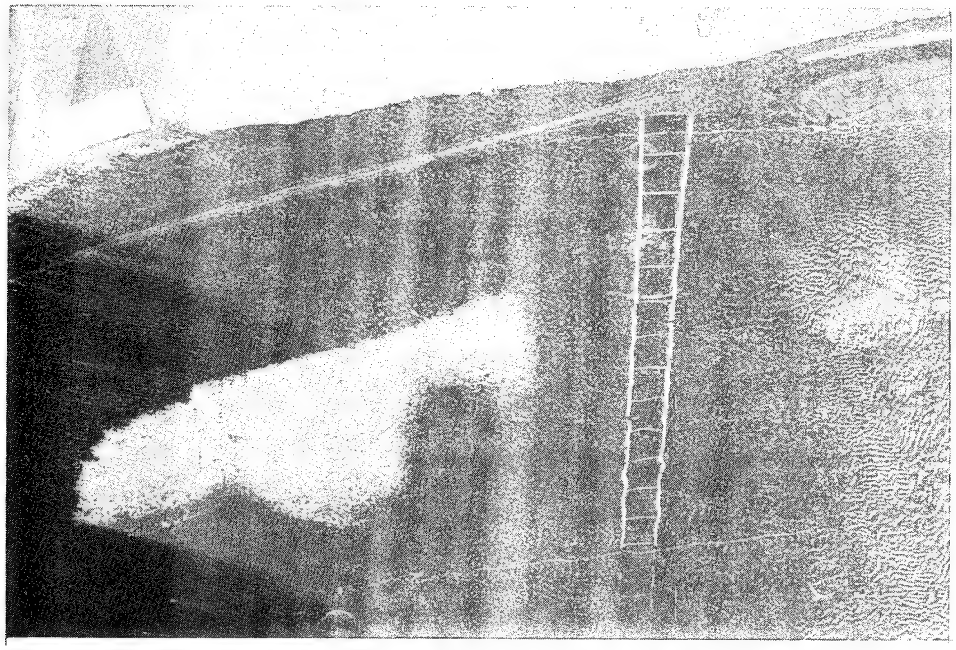


5 hr

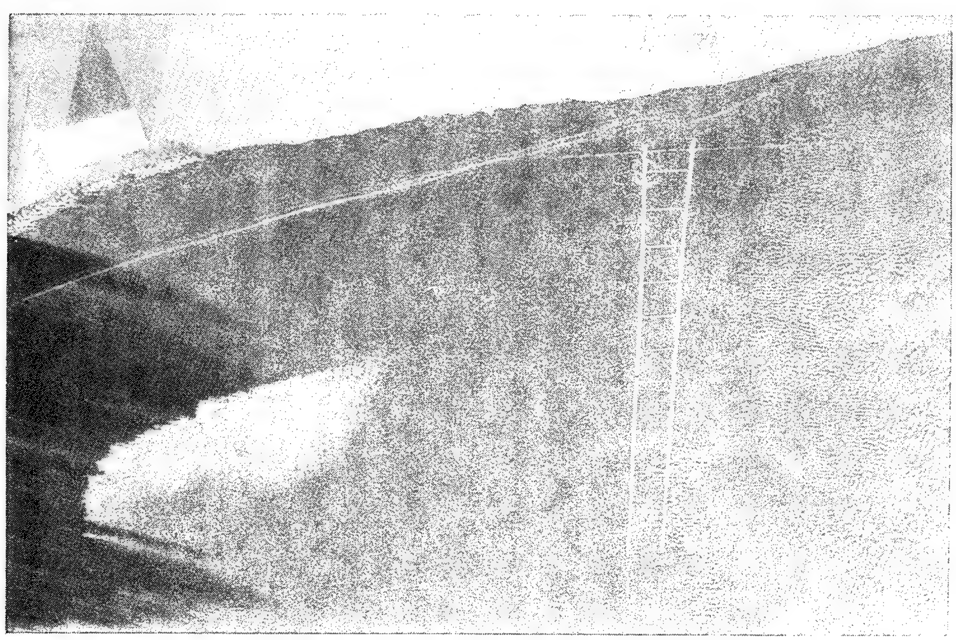


10 hr

Photo 172. Progression of sediment tracer movement along the northern portion of the beach for raised breakwater conditions (5-10 hr)

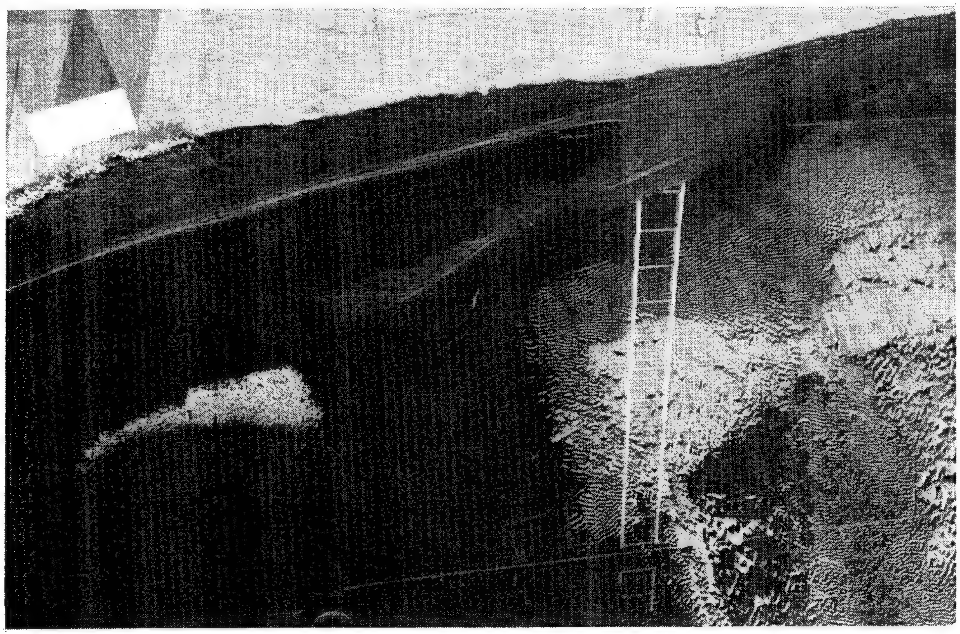


13 hr

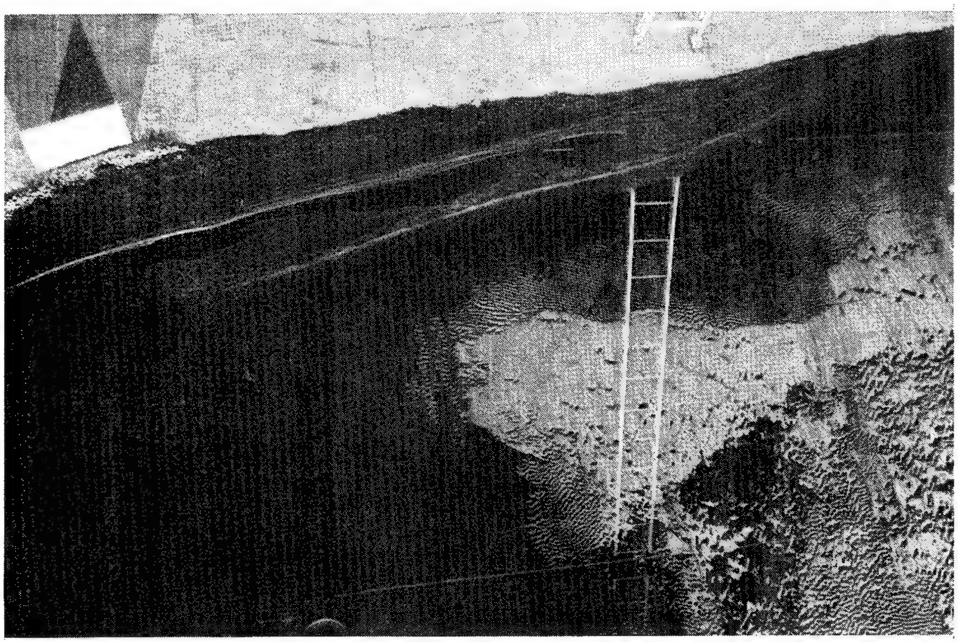


16 hr

Photo 173. Progression of sediment tracer movement along the northern portion of the beach for raised breakwater conditions (13-16 hr)

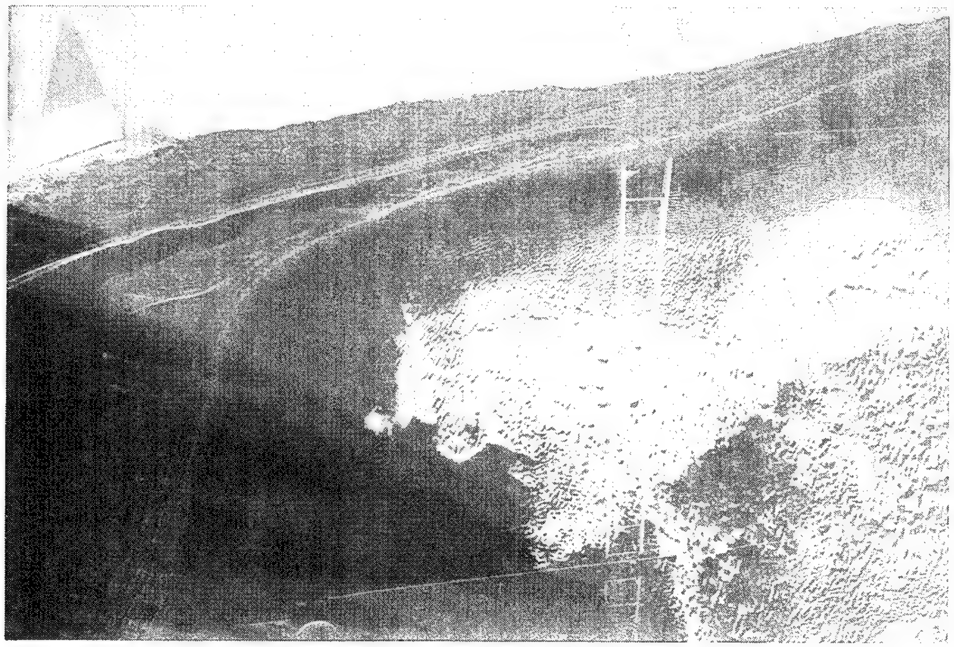


19 hr

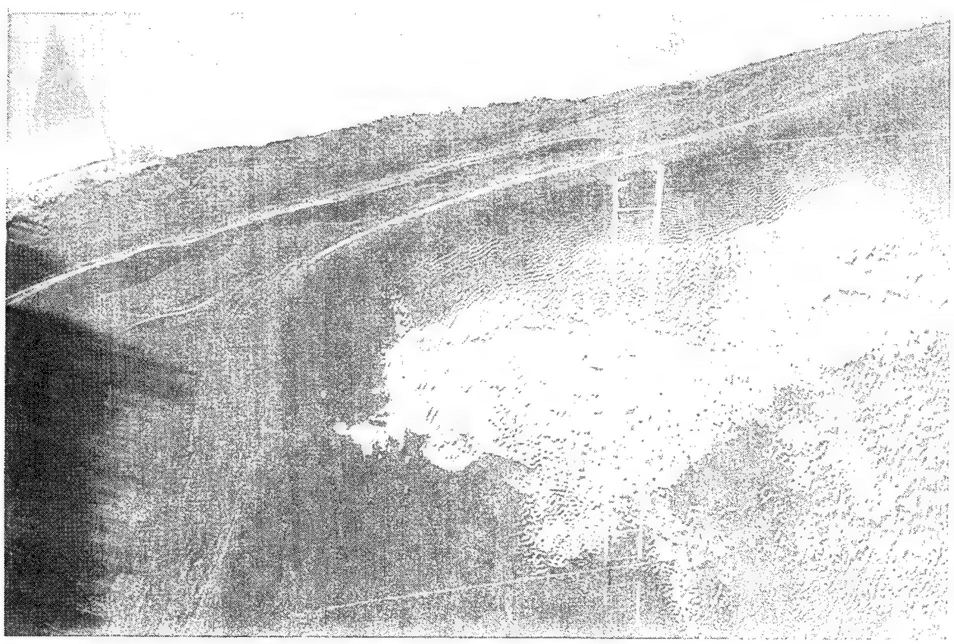


22 hr

Photo 174. Progression of sediment tracer movement along the northern portion of the beach for raised breakwater conditions (19-22 hr)

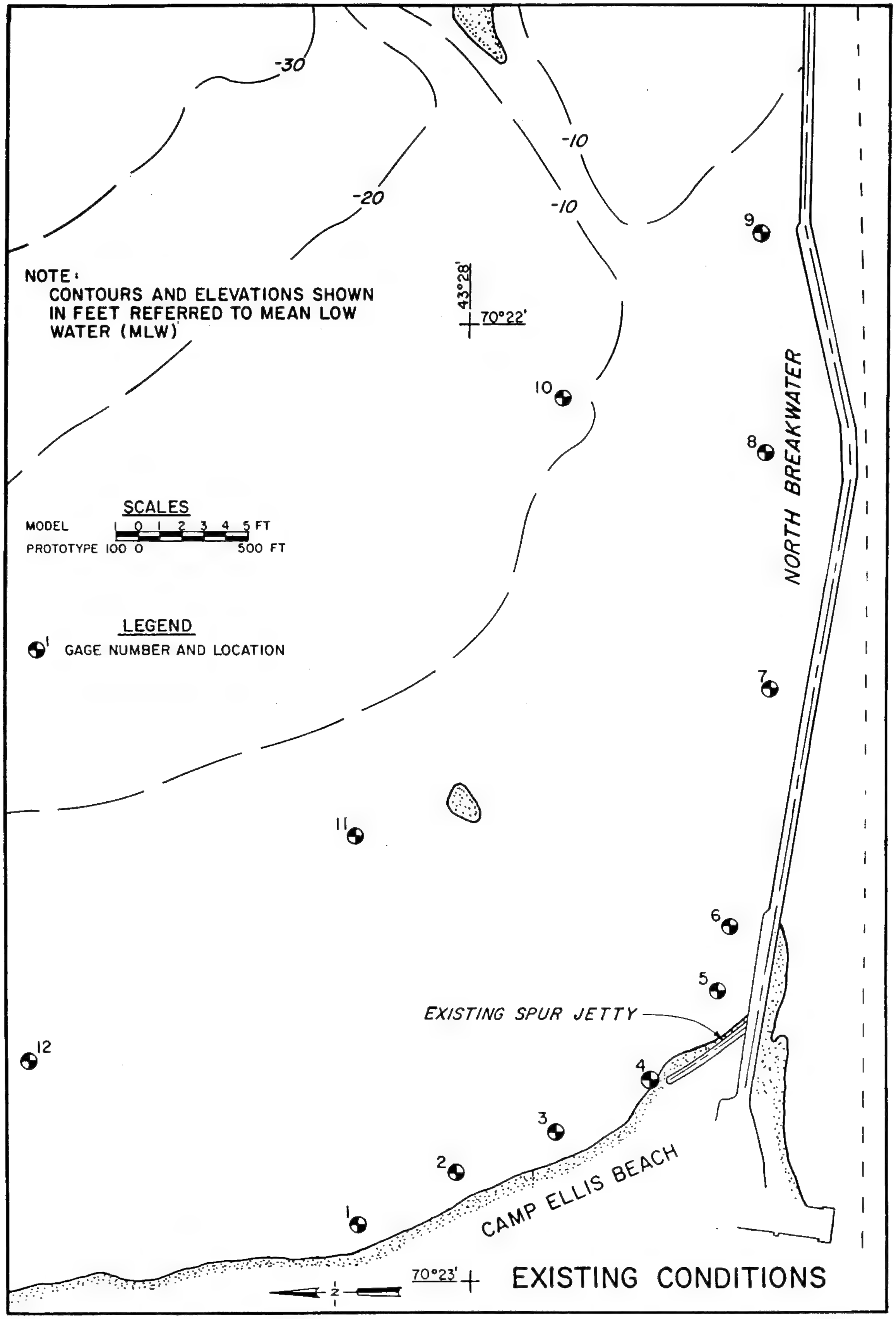


27 hr

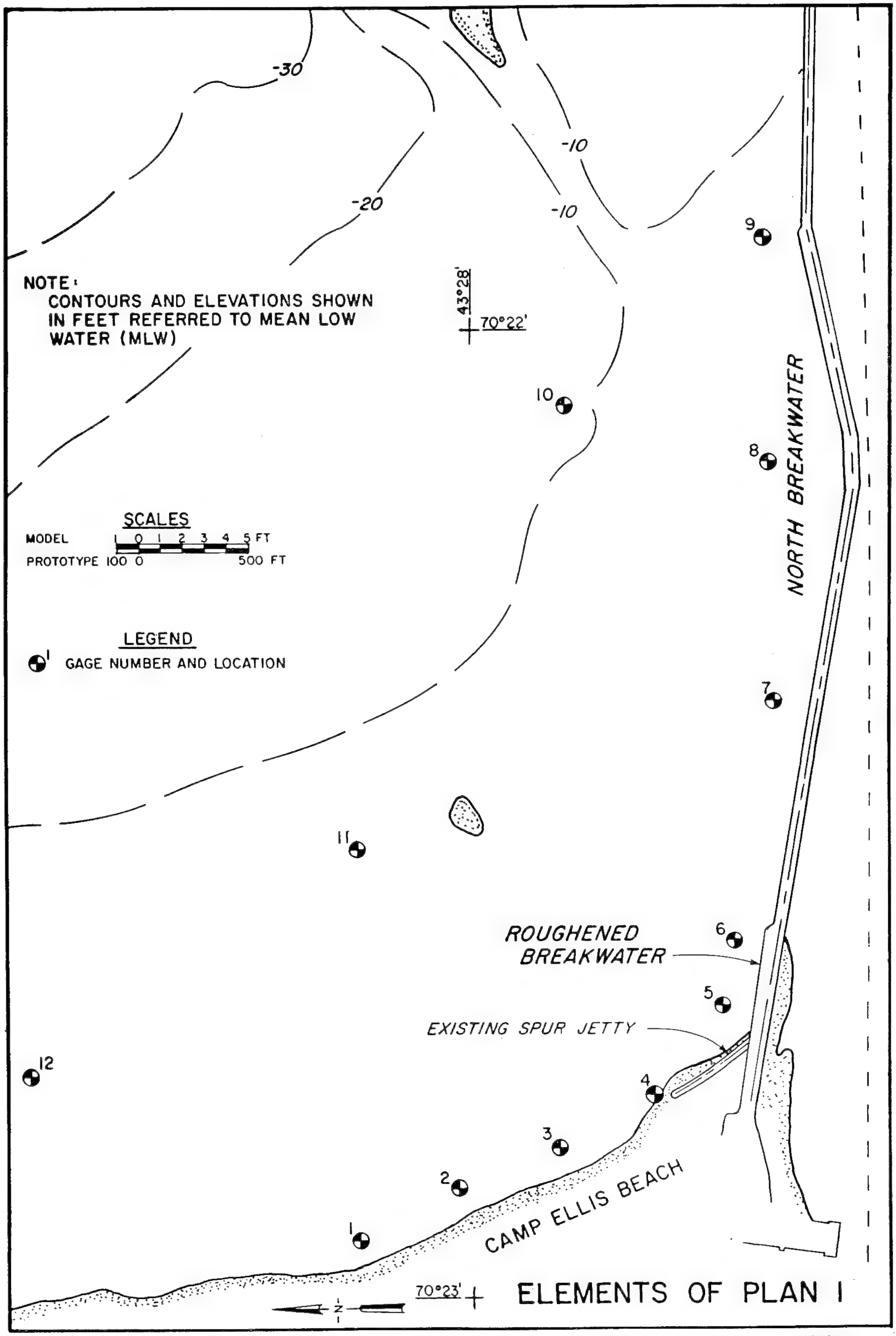


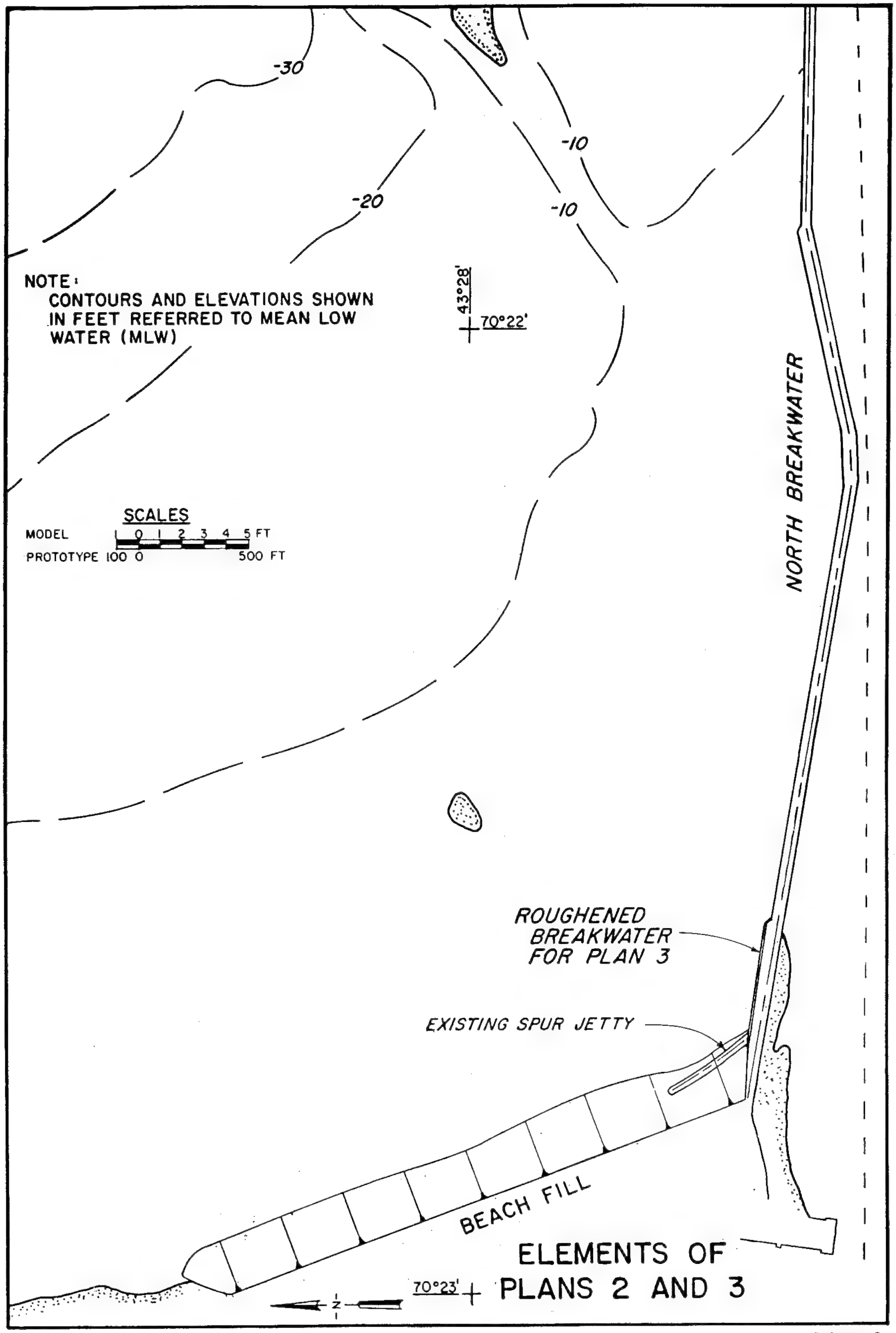
32 hr

Photo 175. Progression of sediment tracer movement along the northern portion of the beach for raised breakwater conditions (27-32 hr)



-30
-20
-10
-10
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
43°28'
70°22'
NORTH BREAKWATER
SCALES
MODEL 1 0 1 2 3 4 5 FT
PROTOTYPE 100 0 500 FT
LEGEND
GAGE NUMBER AND LOCATION
EXISTING SPUR JETTY
CAMP ELLIS BEACH
70°23'
EXISTING CONDITIONS


-30
-20
-10
-10
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
43°28'
70°22'
SCALES
MODEL 1 0 1 2 3 4 5 FT
PROTOTYPE 100 0 500 FT
LEGEND
GAGE NUMBER AND LOCATION
1
2
3
4
5
6
7
8
9
10
11
12
NORTH BREAKWATER
ROUGHENED BREAKWATER
EXISTING SPUR JETTY
CAMP ELLIS BEACH
70°23'
N
ELEMENTS OF PLAN 1



-30
-20
-10
-10
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
43°28'
70°22'
SCALES
MODEL 1 0 1 2 3 4 5 FT
PROTOTYPE 100 0 500 FT
NORTH BREAKWATER
ROUGHENED BREAKWATER FOR PLAN 3
EXISTING SPUR JETTY
BEACH FILL
70°23'
N
ELEMENTS OF PLANS 2 AND 3

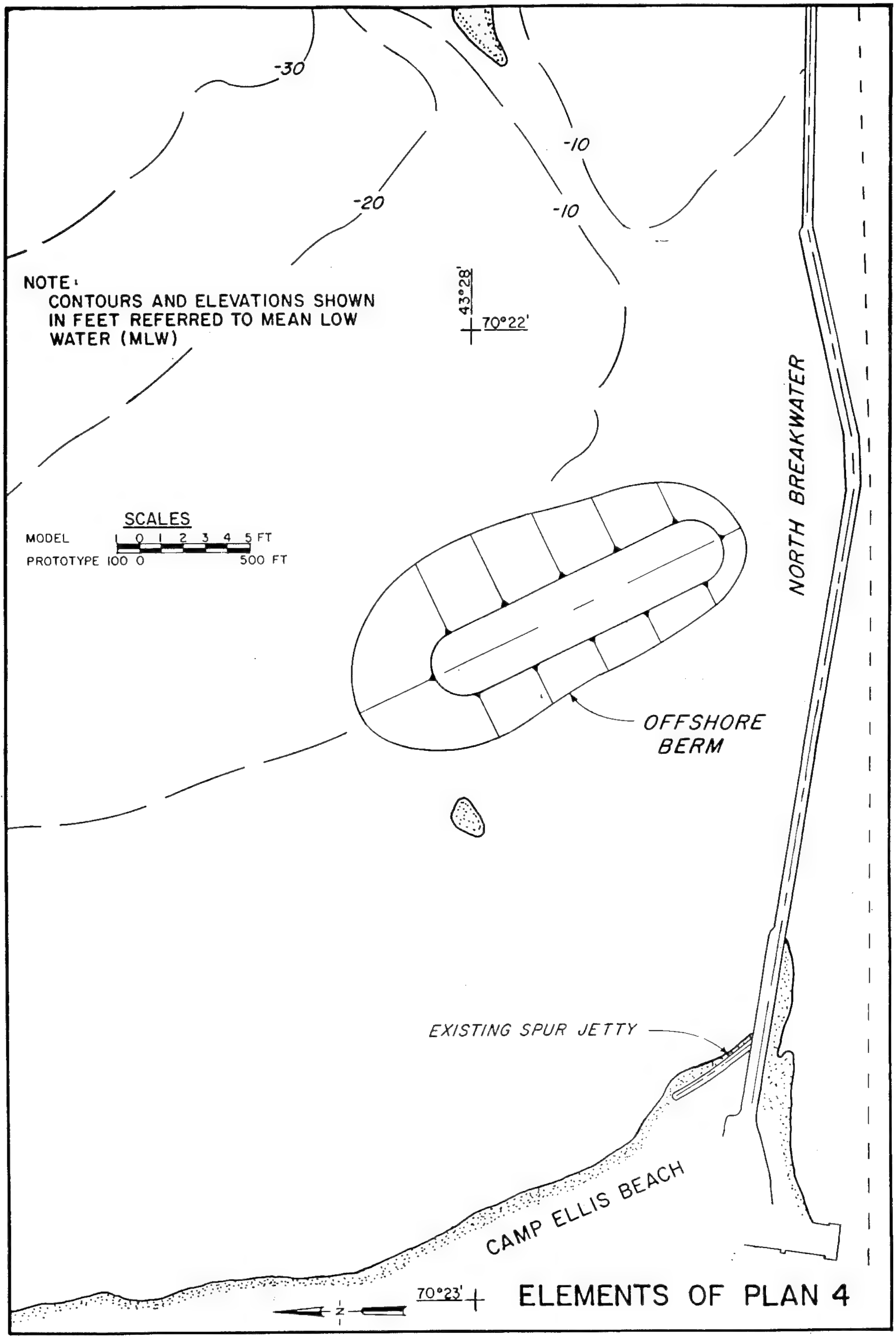
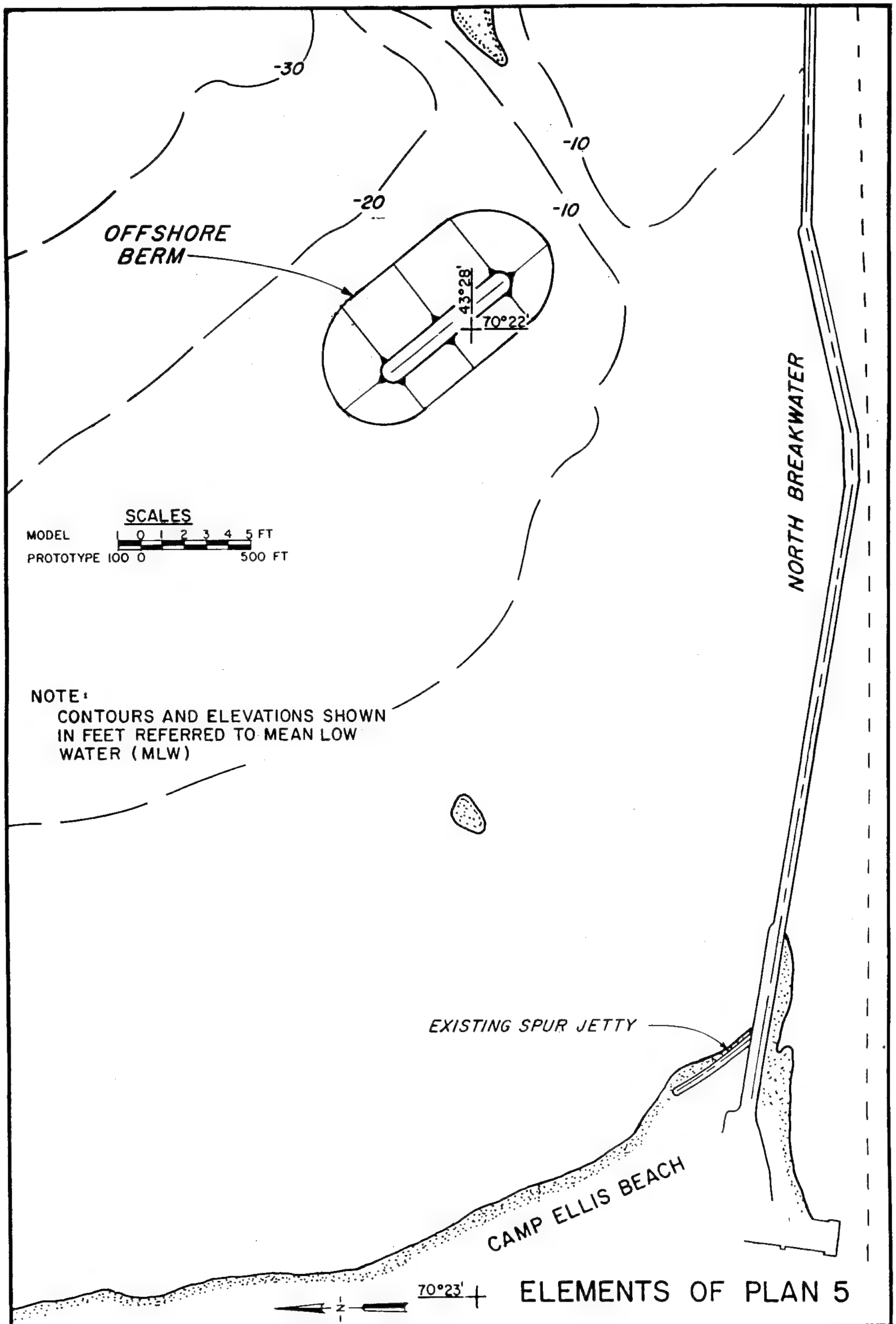
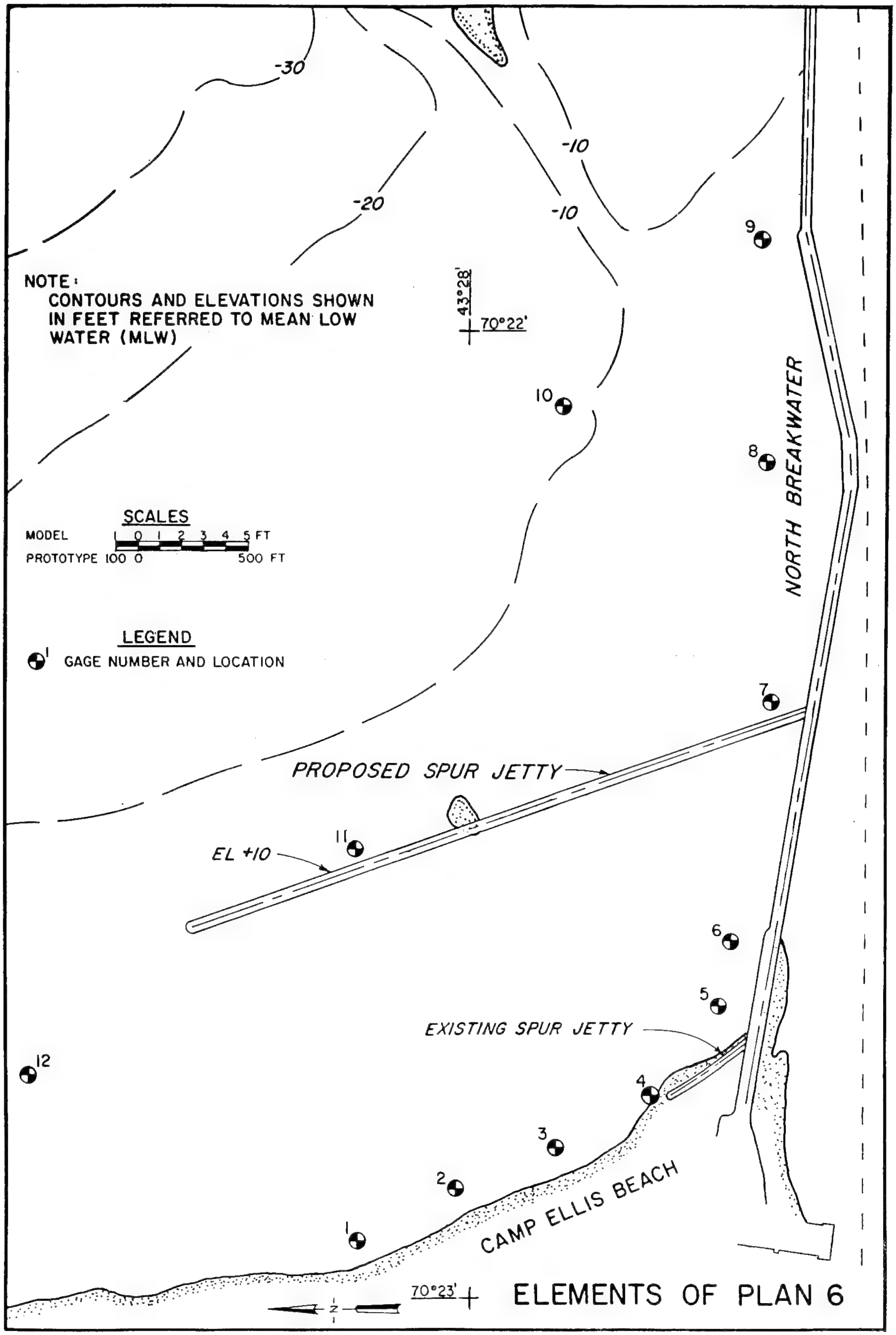
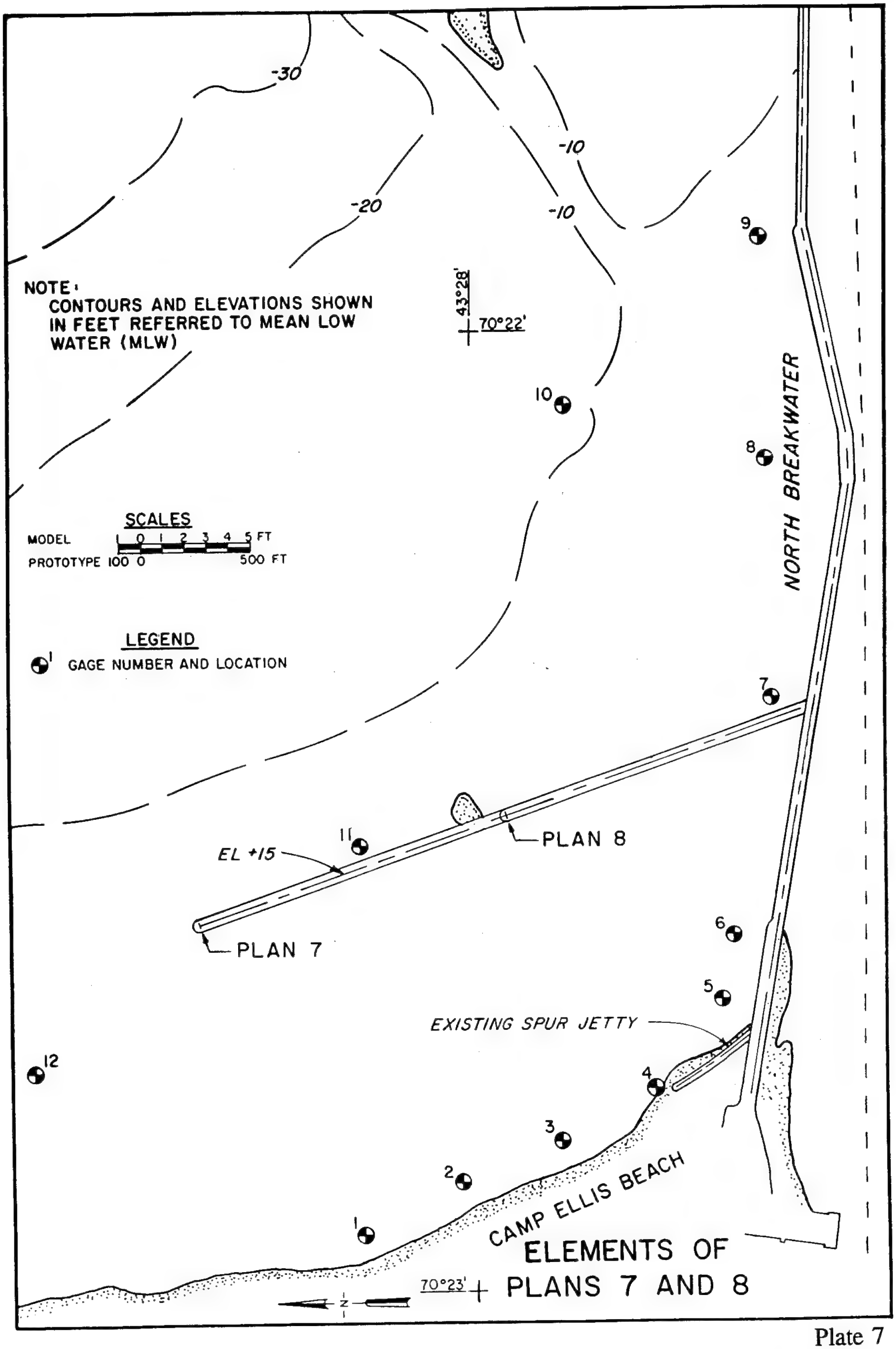

-30
-20
-10
-10
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
43°28'
70°22'
SCALES
MODEL 1 0 1 2 3 4 5 FT
PROTOTYPE 100 0 500 FT
NORTH BREAKWATER
OFFSHORE BERM
EXISTING SPUR JETTY
CAMP ELLIS BEACH
70°23'
N
ELEMENTS OF PLAN 4

Plate 4

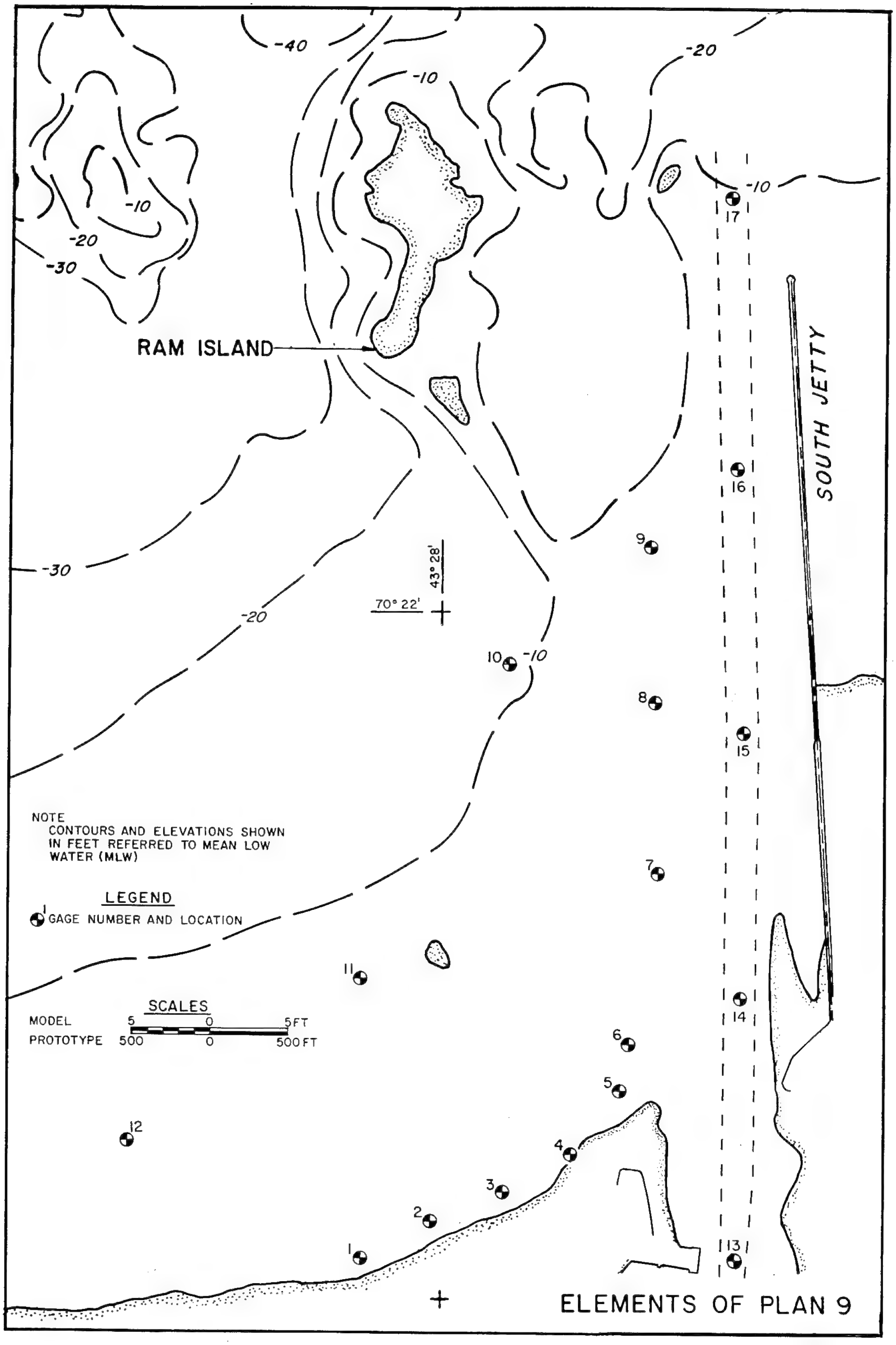


ELEMENTS OF PLAN 5

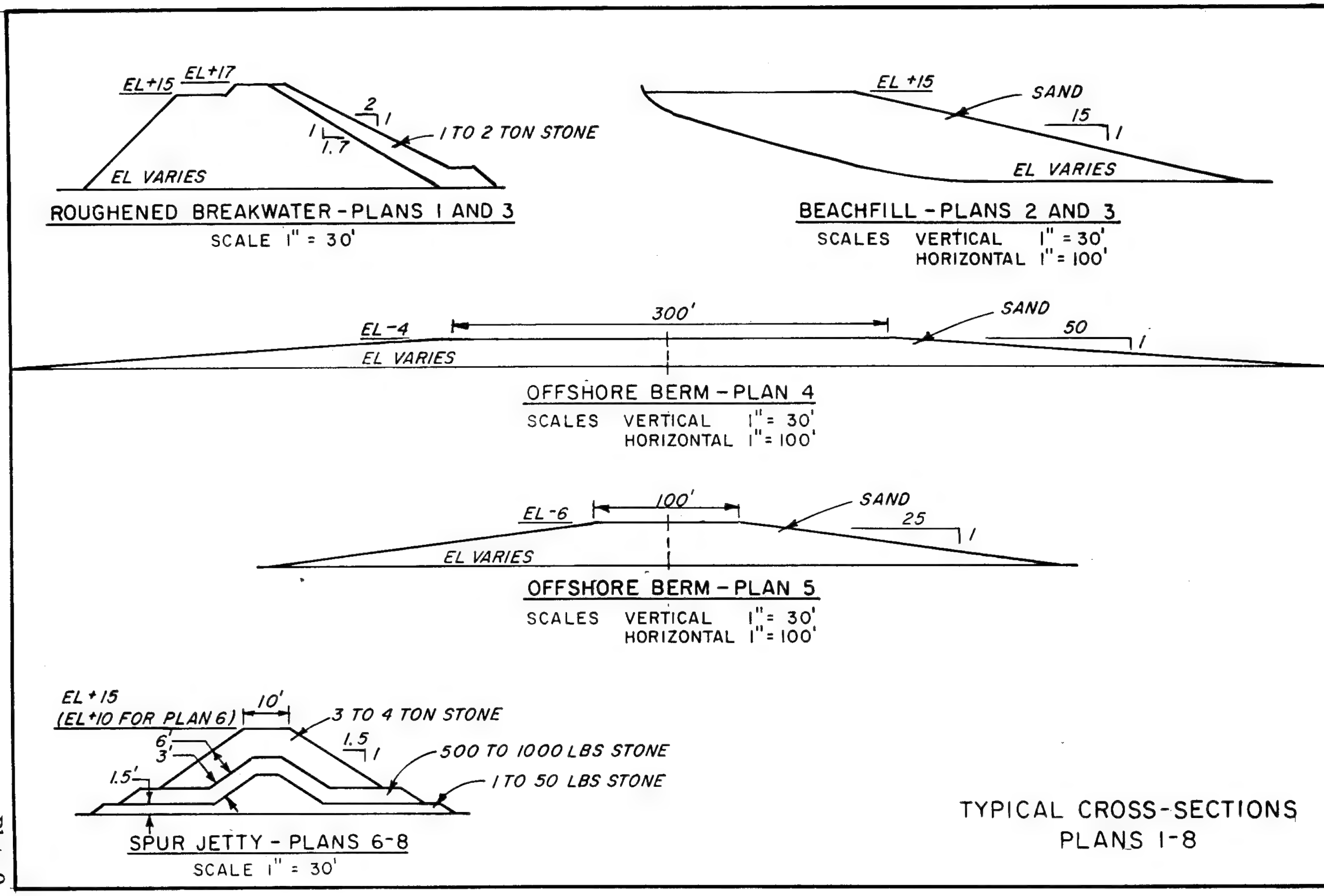

-30
-20
-10
-10
NOTE:
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
43°28'
70°22'
NORTH BREAKWATER
SCALES
MODEL 1 0 1 2 3 4 5 FT
PROTOTYPE 100 0 500 FT
LEGEND
GAGE NUMBER AND LOCATION
PROPOSED SPUR JETTY
EL +10
EXISTING SPUR JETTY
CAMP ELLIS BEACH
1
2
3
4
5
6
7
8
9
10
11
12
N
70°23'
ELEMENTS OF PLAN 6



ELEMENTS OF PLANS 7 AND 8



-40
-10
-20
-10
-20
-30
-10
RAM ISLAND
SOUTH JETTY
17
16
9
-30
-20
43° 28'
70° 22'
10
-10
8
15
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
7
LEGEND
1 GAGE NUMBER AND LOCATION
11
SCALES
MODEL 5 0 5 FT
PROTOTYPE 500 0 500 FT
14
6
5
12
4
3
2
1
13
ELEMENTS OF PLAN 9


EL+15
EL+17
2
1
1
1.7
1 TO 2 TON STONE
EL VARIES
ROUGHENED BREAKWATER - PLANS 1 AND 3
SCALE 1" = 30'
EL +15
SAND
15
1
EL VARIES
BEACHFILL - PLANS 2 AND 3
SCALES VERTICAL 1" = 30'
HORIZONTAL 1" = 100'
300'
SAND
EL -4
50
1
EL VARIES
OFFSHORE BERM - PLAN 4
SCALES VERTICAL 1" = 30'
HORIZONTAL 1" = 100'
100'
SAND
EL -6
25
1
EL VARIES
OFFSHORE BERM - PLAN 5
SCALES VERTICAL 1" = 30'
HORIZONTAL 1" = 100'
EL + 15
(EL +10 FOR PLAN 6)
10'
3 TO 4 TON STONE
6'
3'
1.5
1
500 TO 1000 LBS STONE
1.5'
1 TO 50 LBS STONE
SPUR JETTY - PLANS 6-8
SCALE 1" = 30'
TYPICAL CROSS-SECTIONS
PLANS 1-8

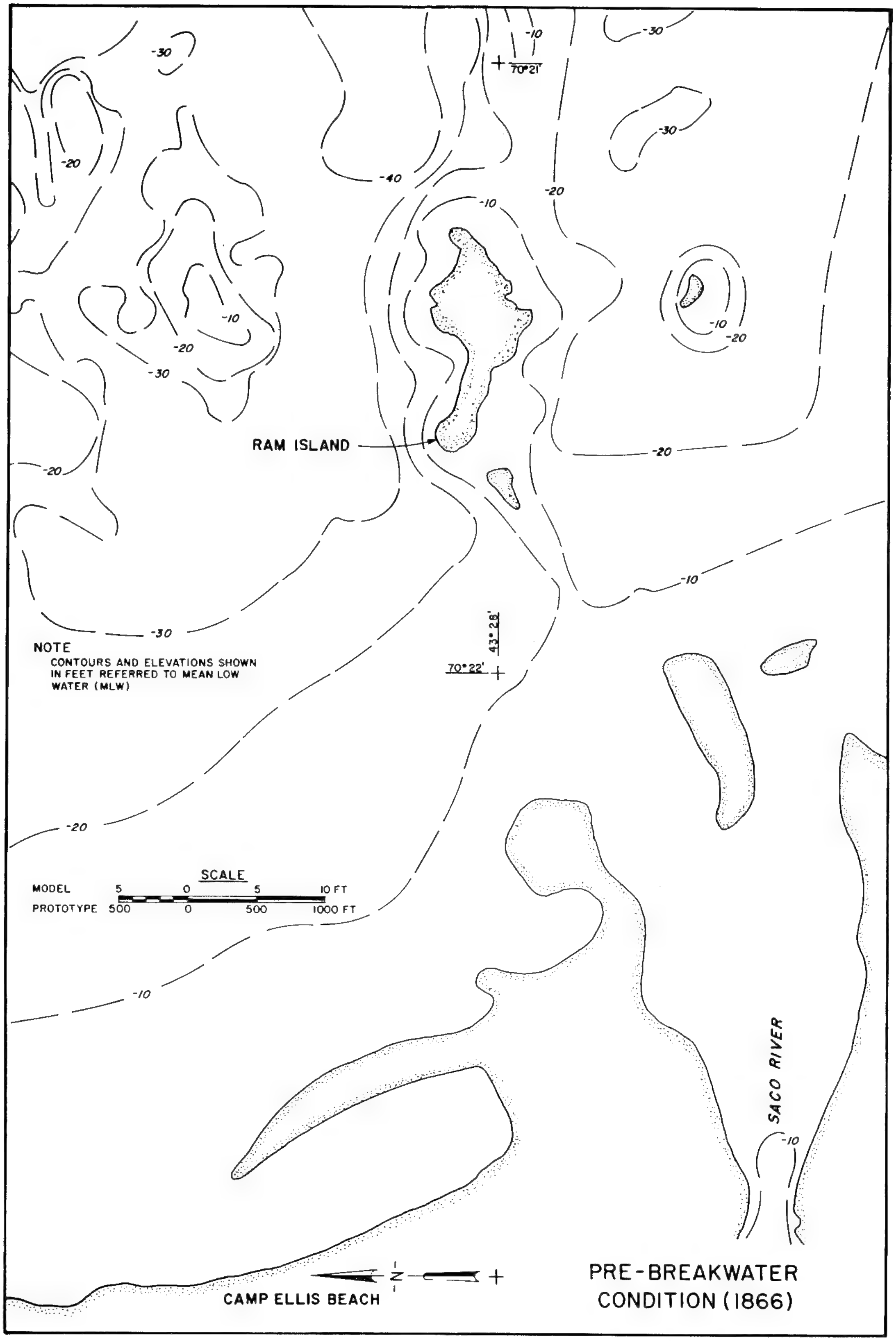

-30
-10
70°21'
-30
-20
-30
-40
-20
-10
-10
-20
-10
-20
-30
-10
-20
RAM ISLAND
-20
-20
-10
-30
43° 28'
70°22'
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
-20
SCALE
MODEL 5 0 5 10 FT
PROTOTYPE 500 0 500 1000 FT
-10
SACO RIVER
-10
N
CAMP ELLIS BEACH
PRE-BREAKWATER CONDITION (1866)

Plate 10

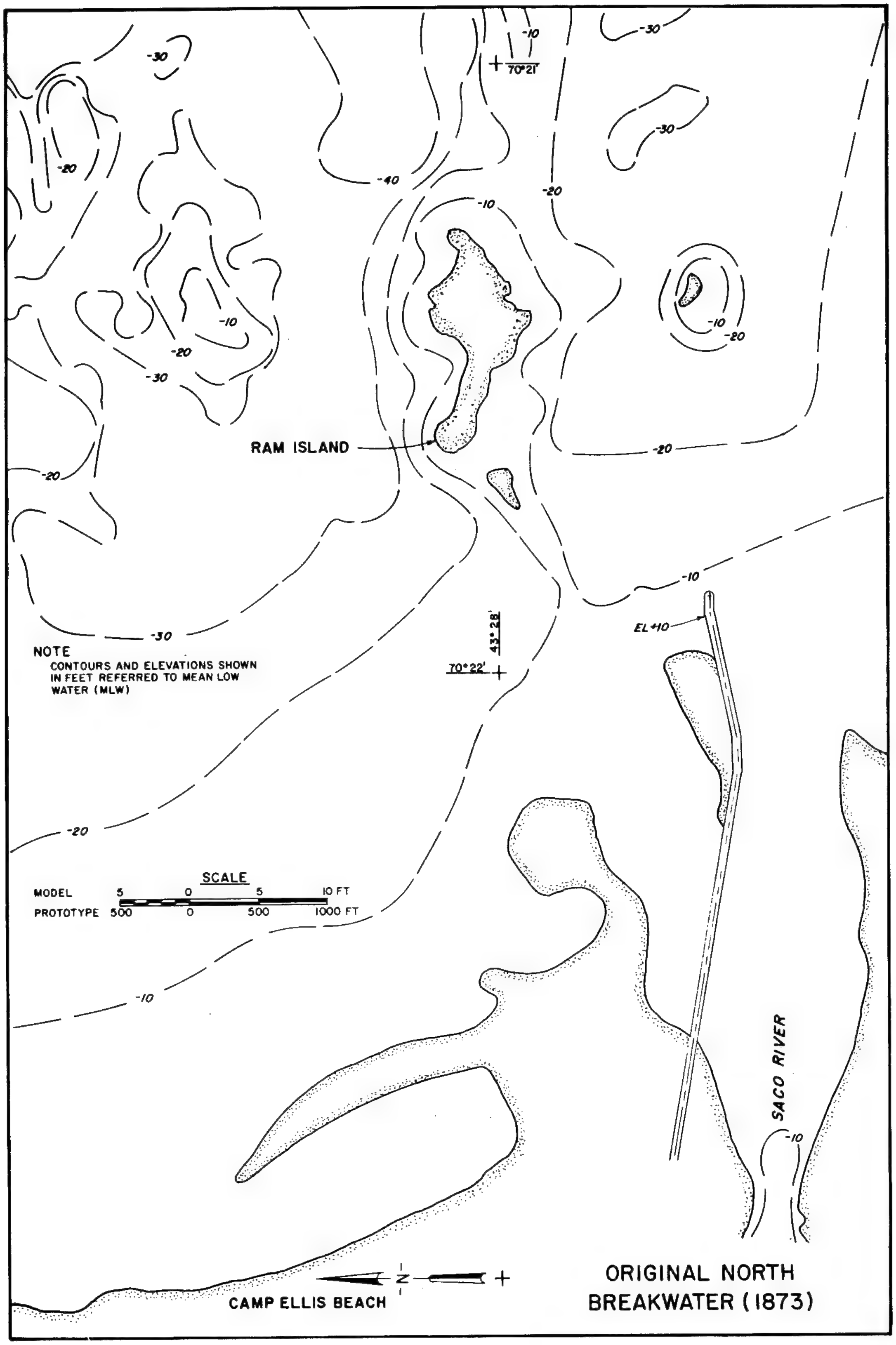
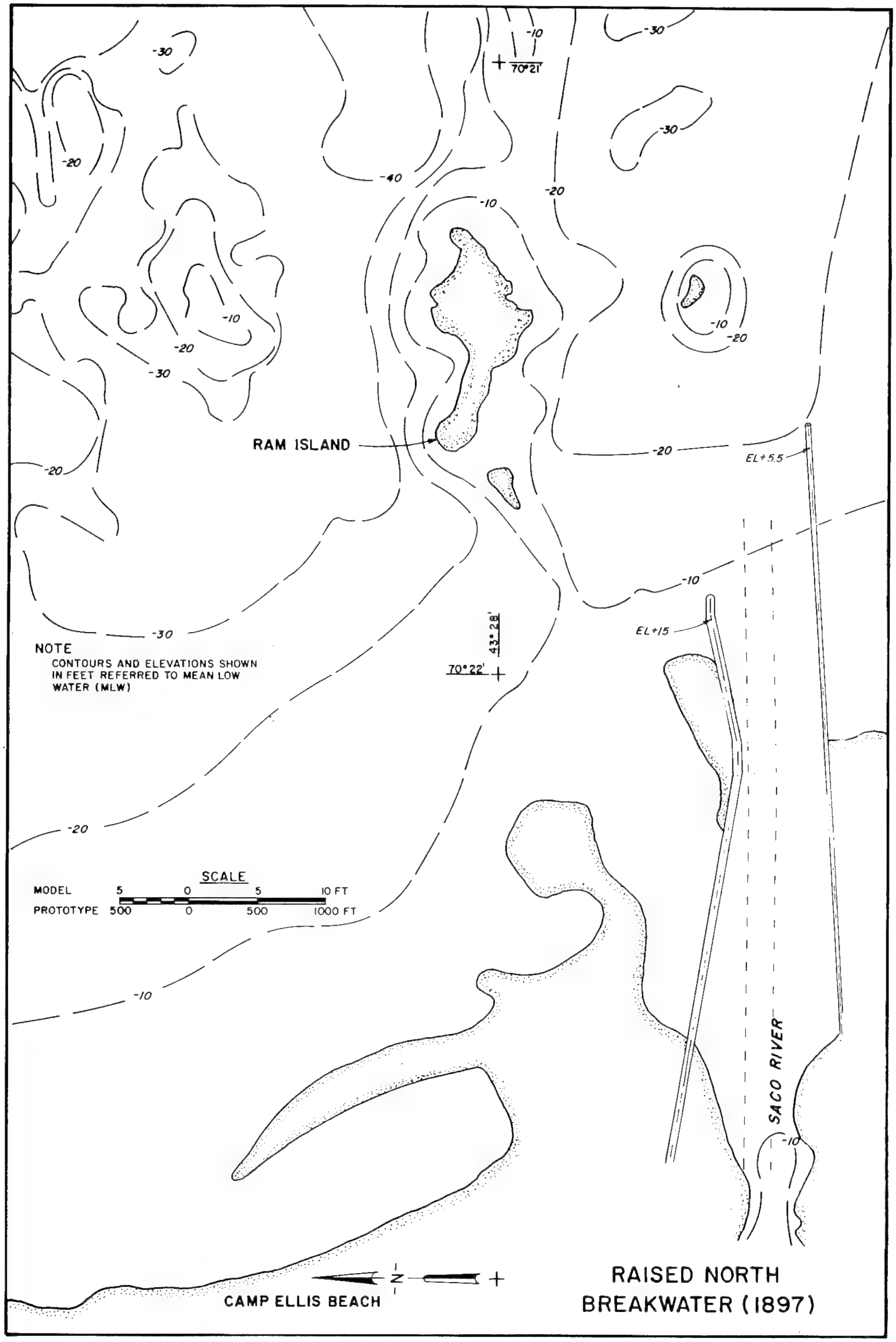

-30
-10
70°21'
-30
-30
-20
-40
-20
-10
-10
-20
-20
-10
-30
-20
RAM ISLAND
-20
-20
-10
EL+10
-30
43°28'
70°22'
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
-20
SCALE
MODEL 5 0 5 10 FT
PROTOTYPE 500 0 500 1000 FT
-10
SACO RIVER
-10
N
CAMP ELLIS BEACH
ORIGINAL NORTH BREAKWATER (1873)

Plate 11



-30
-10
70°21'
-30
-30
-20
-40
-10
-20
-10
-20
-10
-20
-30
RAM ISLAND
-20
-20
EL+5.5
-10
EL+15
-30
43°28'
70°22'
NOTE
CONTOURS AND ELEVATIONS SHOWN IN FEET REFERRED TO MEAN LOW WATER (MLW)
-20
SCALE
MODEL 5 0 5 10 FT
PROTOTYPE 500 0 500 1000 FT
-10
SACO RIVER
-10
N
CAMP ELLIS BEACH
RAISED NORTH BREAKWATER (1897)

Plate 12

Appendix A
Saco Bay Nearshore Wave Estimates

Introduction

This section of the report describes procedures and results of the nearshore wave estimates used in the Saco Bay physical model study. Included are an overview presenting the scope of the numerical wave estimation, a general description of the Saco Bay wave climate and available information, numerical model selection, description of the numerical wave model, and procedures used to develop various input and output in this task. A brief discussion of the tabular and graphical results obtained by different analysis methods is also presented.

Scope

The purpose of the numerical wave modeling task was to develop nearshore wave conditions for use in the subsequent physical model study for Saco Bay. The experimental part of the study was to investigate waves and wave motion in the immediate vicinity of two jetties and adjacent beaches to the north of the mouth of Saco River in a controlled laboratory setup.

Figure A1 shows the part of the numerical model grid for Saco Bay that was investigated in a scaled laboratory study. It shows the location of several transects (TR) selected for numerical model output in the nearshore region where erosion problems have been observed. In the laboratory tests, a wave generator was positioned along TR 3. The wave generator was driven with wave input to investigate the effects of waves on the coastline, sediment movement, and jetties. Therefore, the main objective of the numerical modeling was to provide wave conditions to be used in the laboratory tests as input to the wave generator. Numerical model output was needed only at TR 3. Output provided at TR 1, 2, 5, 6, and 7 was only for information purposes and may be used to compare laboratory measurements and numerical model results.

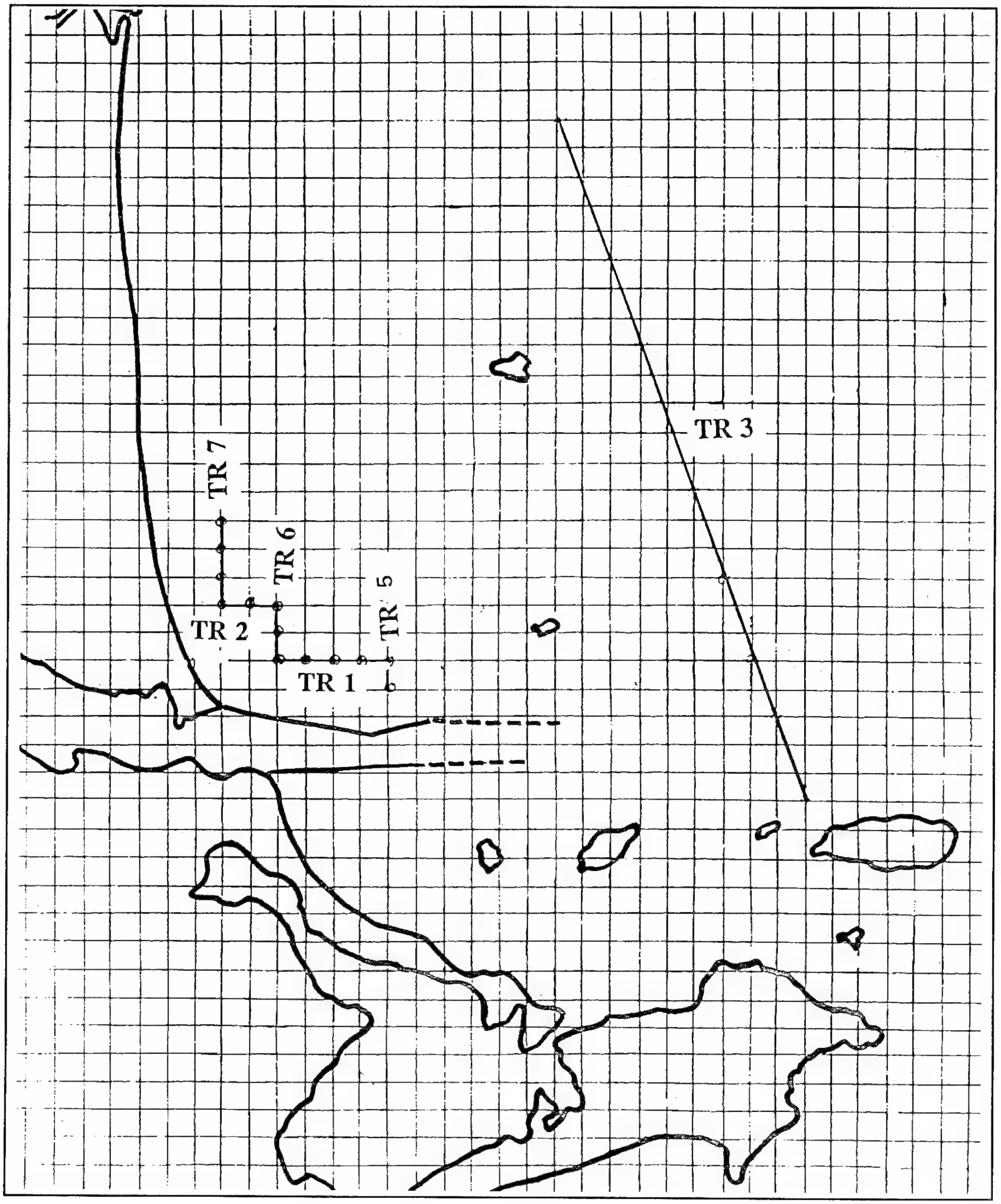


Figure A1. Transects (TR) for model output

Wave Climate

Table A1 lists the preliminary input wave conditions at the deepwater offshore boundary for the numerical model used in this study for quantifying the

Table A1
Saco Bay Offshore Input Wave Conditions for Numerical Model

Direction (deg)			
WIS	Model	Period (sec)	Amplitude (ft)
90	0	5,7,9,11,13,15	1
135	-45	5,7	1
45	45	5,7	1
67.5	22.5	5,7,9,11	1
112.5	-22.5	5,7,9,11,13,15	1
103	-13	5,7,9,11,13,15,17	1

wave propagation/transformation processes which occur inside the Saco Bay area. These data were based on the wave climate historical information for Saco Bay. Table A2 lists a summary of the historical wave climate for Saco Bay. The Saco Bay wave climate was characterized by storms within the Wave Information Study (WIS) 20-year hindcast period, 1956-1975. Input wave conditions to the numerical model were specified using the WIS revised hindcast of the North Atlantic sea at WIS station 99 (43.50 N, 70.25 W). This station is approximately 9.7 km (6 miles) offshore east of the Saco River mouth and roughly 3.2 km (2 miles) into Saco Bay. All WIS hindcast stations for the U.S. Atlantic coast are shown in Figure A2. Location of WIS stations and the weather buoys near the study area are shown in Figure A3. All WIS wave hindcast summary data for station 99 are presented in Table A2. Additional hindcast simulations, results of which are also listed in Table 2, were specifically performed for this task to construct wave conditions centered about 67.5-, 112.5-, and 103.0-deg incident wave angles. These angles, as will be described later, correspond respectively to 22.5-, -22.5-, and -13.0-deg wave input to the numerical model.

Nearshore wave measurements in Saco Bay are not available, and therefore, the numerical model had to be run with available data offshore. The only available offshore wave data source for Saco Bay was the deepwater buoys operated by the National Oceanic and Atmospheric Administration's (NOAA's) National Data Buoy Center (NDBC). As shown in Figure A3, climatological information for the Saco Bay area may be obtained from the nearest NDBC buoy, #44007 (Gilhousen et al. 1986).[1] However, since WIS hindcast estimates are routinely compared to the NDBC buoy measurements, this establishes a high degree of confidence in the WIS database. Therefore, it was decided to use WIS hindcast data directly in this study. Noting that the NDBC wave buoy measurements may lack wave direction information when nondirectional buoys are used, WIS directional estimates could not be compared

[1] References cited in this appendix are included in the References at the end of the main text.

Table A2

WIS ATLANTIC REVISION 1956 - 1975
LAT: 43.50 N, LONG: 70.25 W, DEPTH: 18 M
SUMMARY OF WAVE INFORMATION BY MONTH

STATION: 99

OCCURRENCES OF WAVE HEIGHT BY MONTH FOR ALL YEARS

Hmo(m)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
0.00 - 0.49	556	614	718	910	1081	1094	1407	1510	1007	810	642	593	10942
0.50 - 0.99	1491	1383	1508	1932	2325	2574	2740	2799	2538	2084	1597	1424	24395
1.00 - 1.49	1188	1226	1392	1158	1097	843	629	518	862	1298	1123	1081	12415
1.50 - 1.99	907	711	821	502	380	238	170	123	268	515	769	920	6324
2.00 - 2.49	435	339	318	201	61	40	14	10	91	168	406	524	2607
2.50 - 2.99	234	130	114	67	16	10	.	.	26	59	155	202	1013
3.00 - 3.49	97	66	50	22	.	1	.	.	5	14	64	116	435
3.50 - 3.99	27	30	29	4	.	.	.	.	3	4	19	54	170
4.00 - 4.49	12	12	7	4	.	.	.	.	.	3	19	22	79
4.50 - 4.99	5	4	2	.	.	.	.	.	.	4	4	12	31
5.00 - 5.49	8	4	1	.	.	.	.	.	.	1	2	5	21
5.50 - 5.99	.	1	.	.	.	.	.	.	.	.	.	4	5
6.00 - 6.49	.	.	.	.	.	.	.	.	.	.	.	3	3
6.50 - 6.99	.	.	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.49	.	.	.	.	.	.	.	.	.	.	.	.	0
7.50 - 7.99	.	.	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.49	.	.	.	.	.	.	.	.	.	.	.	.	0
8.50 - 8.99	.	.	.	.	.	.	.	.	.	.	.	.	0
9.00 - 9.49	.	.	.	.	.	.	.	.	.	.	.	.	0
9.50 - 9.99	.	.	.	.	.	.	.	.	.	.	.	.	0
10.00 - GREATER	.	.	.	.	.	.	.	.	.	.	.	.	0
TOTAL	4960	4520	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960	58440

STATION: 99

OCCURRENCES OF PEAK PERIOD BY MONTH FOR ALL YEARS

Tp(sec)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
3.0 - 3.9	572	619	686	771	788	831	1052	1163	638	689	570	447	8826
4.0 - 4.9	1183	1078	1258	1124	893	1032	876	1051	1020	1274	947	950	12686
5.0 - 5.9	1063	852	980	648	721	770	746	550	639	842	887	1019	9717
6.0 - 6.9	511	374	417	278	412	463	290	351	326	332	423	443	4620
7.0 - 7.9	206	260	306	283	429	685	717	760	531	418	314	299	5208
8.0 - 8.9	227	257	294	339	787	579	656	563	743	538	302	262	5547
9.0 - 9.9	334	243	278	540	609	309	506	375	480	431	465	313	4883
10.0 - 10.9	361	281	323	448	234	93	82	85	249	228	403	485	3272
11.0 - 11.9	328	245	200	264	68	31	17	46	143	125	349	464	2280
12.0 - 12.9	128	210	142	77	10	7	14	13	31	61	97	205	995
13.0 - 13.9	43	81	51	23	8	.	4	3	.	19	32	56	320
14.0 - 14.9	3	10	17	5	.	.	.	.	.	2	8	17	62
15.0 - 15.9	.	10	5	.	.	.	.	.	.	1	3	.	19
16.0 - 16.9	.	.	.	.	.	.	.	.	.	.	.	.	0
17.0 - 17.9	.	.	.	.	.	.	.	.	.	.	.	.	0
18.0 - 18.9	.	.	.	.	.	.	.	.	.	.	.	.	0
19.0 - 19.9	.	.	.	.	.	.	.	.	.	.	.	.	0
20.0 - LONGER	1	.	3	.	1	.	.	.	.	.	.	.	5
TOTAL	4960	4520	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960	58440

STATION: 99

OCCURRENCES OF PEAK DIRECTION BY MONTH FOR ALL YEARS

Dp(deg) DIRECTION BAND & CENTER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
348.75 - 11.24 (0.0)	234	172	237	222	96	58	32	68	110	160	197	178	1764
11.25 - 33.74 (22.5)	137	100	102	108	38	36	17	40	53	83	71	90	875
33.75 - 56.24 (45.0)	73	47	85	35	22	23	.	33	23	63	44	64	512
56.25 - 78.74 (67.5)	57	69	90	58	33	44	3	13	40	79	73	86	645
78.75 - 101.24 (90.0)	123	154	187	104	132	39	17	28	85	172	131	200	1372
101.25 - 123.74 (112.5)	437	519	491	460	534	143	197	291	703	450	560	609	5394
123.75 - 146.24 (135.0)	969	946	1072	1258	1541	1436	1566	1439	1591	1258	1181	1298	15555
146.25 - 168.74 (157.5)	439	474	535	659	681	765	674	689	410	517	454	383	6680
168.75 - 191.24 (180.0)	265	187	259	347	385	447	387	266	311	361	475	292	3982
191.25 - 213.74 (202.5)	272	151	180	225	346	478	518	435	364	298	239	175	3681
213.75 - 236.24 (225.0)	152	101	92	151	236	377	389	408	217	222	162	140	2647
236.25 - 258.74 (247.5)	111	132	79	119	166	235	295	292	119	177	113	109	1947
258.75 - 281.24 (270.0)	363	317	268	267	272	345	405	428	237	395	331	285	3913
281.25 - 303.74 (292.5)	430	423	408	291	188	161	232	226	233	289	309	332	3522
303.75 - 326.24 (315.0)	491	451	489	270	186	135	149	182	178	249	278	397	3455
326.25 - 348.74 (337.5)	407	277	386	226	104	78	79	122	126	187	182	322	2496
TOTAL	4960	4520	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960	58440

(Sheet 1 of 5)

Table A2 (Continued)

WIS ATLANTIC REVISION 1956 - 1975
LAT: 43.50 N, LONG: 70.25 W, DEPTH: 18 M
OCCURRENCES OF WAVE HEIGHT AND PEAK PERIOD FOR 45-DEG DIRECTION BANDS

STATION: 99 (337.50 - 22.49) 0.0 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	2069	.	.	.	.	.	.	.	.	.	2069
1.00 - 1.99	819	384	.	.	.	.	.	.	.	.	1203
2.00 - 2.99	.	108	.	.	.	.	.	.	.	.	108
3.00 - 3.99	.	.	.	.	.	.	.	.	.	.	0
4.00 - 4.99	.	.	.	.	.	.	.	.	.	.	0
5.00 - 5.99	.	.	.	.	.	.	.	.	.	.	0
6.00 - 6.99	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	2888	492	0	0	0	0	0	0	0	0	3380

STATION: 99 (22.50 - 67.49) 45.0 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	669	38	.	.	.	.	.	.	.	.	707
1.00 - 1.99	274	131	.	.	.	.	.	.	.	.	405
2.00 - 2.99	.	80	.	.	.	.	.	.	.	.	80
3.00 - 3.99	.	3	.	.	.	.	.	.	.	.	3
4.00 - 4.99	.	.	.	.	.	.	.	.	.	.	0
5.00 - 5.99	.	.	.	.	.	.	.	.	.	.	0
6.00 - 6.99	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	943	252	0	0	0	0	0	0	0	0	1195

STATION: 99 (67.50 - 112.49) 90.0 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	715	326	42	1	.	.	.	.	.	.	1084
1.00 - 1.99	102	633	218	20	1	.	.	.	.	.	974
2.00 - 2.99	.	88	192	54	3	.	.	.	.	.	337
3.00 - 3.99	.	1	51	41	8	.	.	.	.	.	101
4.00 - 4.99	.	.	1	14	11	.	.	.	.	.	26
5.00 - 5.99	.	.	.	.	5	4	.	.	.	.	9
6.00 - 6.99	.	.	.	.	1	.	.	.	.	.	1
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	817	1048	504	130	29	4	0	0	0	0	2532

STATION: 99 (112.50 - 157.49) 135.0 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	1247	1938	7389	5410	1940	195	4	.	.	.	18123
1.00 - 1.99	106	1167	1564	1859	855	110	4	.	.	.	5665
2.00 - 2.99	.	101	467	555	279	38	8	.	.	.	1448
3.00 - 3.99	.	.	47	169	106	25	3	.	.	.	350
4.00 - 4.99	.	.	.	27	52	5	.	.	.	.	84
5.00 - 5.99	.	.	.	1	12	4	.	.	.	.	17
6.00 - 6.99	.	.	.	.	1	1	.	.	.	.	2
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	1353	3206	9467	8021	3245	378	19	0	0	0	25689

STATION: 99 (157.50 - 202.49) 180.0 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	2277	850	12	.	1	.	.	.	.	.	3140
1.00 - 1.99	226	2650	117	.	.	.	.	.	.	.	2993
2.00 - 2.99	.	254	514	.	.	.	.	.	.	.	768
3.00 - 3.99	.	.	113	4	.	.	.	.	.	.	117
4.00 - 4.99	.	.	.	.	.	.	.	.	.	.	0
5.00 - 5.99	.	.	.	.	.	.	.	.	.	.	0
6.00 - 6.99	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	2503	3754	756	4	1	0	0	0	0	0	7018

(Sheet 2 of 5)

Table A2 (Continued)

WIS ATLANTIC REVISION 1956 - 1975
LAT: 43.50 N, LONG: 70.25 W, DEPTH: 18 M
OCCURRENCES OF WAVE HEIGHT AND PEAK PERIOD FOR 45-DEG DIRECTION BANDS

STATION: 99 (202.50 - 247.49) 225.0 DEG

Hmo(m) \ Tp(sec)	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	2853	338	.	.	.	.	.	.	.	.	3191
1.00 - 1.99	172	1858	.	.	.	.	.	.	.	.	2030
2.00 - 2.99	.	212	10	.	.	.	.	.	.	.	222
3.00 - 3.99	.	.	5	.	.	.	.	.	.	.	5
4.00 - 4.99	.	.	.	.	.	.	.	.	.	.	0
5.00 - 5.99	.	.	.	.	.	.	.	.	.	.	0
6.00 - 6.99	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	3025	2408	15	0	0	0	0	0	0	0	5448

STATION: 99 (247.50 - 292.49) 270.0 DEG

Hmo(m) \ Tp(sec)	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	4367	.	.	.	.	.	.	.	.	5	4372
1.00 - 1.99	1427	633	.	.	.	.	.	.	.	.	2060
2.00 - 2.99	.	157	.	.	.	.	.	.	.	.	157
3.00 - 3.99	.	4	.	.	.	.	.	.	.	.	4
4.00 - 4.99	.	.	.	.	.	.	.	.	.	.	0
5.00 - 5.99	.	.	.	.	.	.	.	.	.	.	0
6.00 - 6.99	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	5794	794	0	0	0	0	0	0	0	5	6593

STATION: 99 (292.50 - 337.49) 315.0 DEG

Hmo(m) \ Tp(sec)	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	2651	.	.	.	.	.	.	.	.	.	2651
1.00 - 1.99	1538	1871	.	.	.	.	.	.	.	.	3409
2.00 - 2.99	.	500	.	.	.	.	.	.	.	.	500
3.00 - 3.99	.	12	13	.	.	.	.	.	.	.	25
4.00 - 4.99	.	.	.	.	.	.	.	.	.	.	0
5.00 - 5.99	.	.	.	.	.	.	.	.	.	.	0
6.00 - 6.99	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	4189	2383	13	0	0	0	0	0	0	0	6585

STATION: 99 ALL DIRECTIONS

Hmo(m) \ Tp(sec)	3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	16848	3490	7443	5411	1941	195	4	.	.	5	35337
1.00 - 1.99	4664	9327	1899	1879	856	110	4	.	.	.	18739
2.00 - 2.99	.	1500	1183	609	282	38	8	.	.	.	3620
3.00 - 3.99	.	20	229	214	114	25	3	.	.	.	605
4.00 - 4.99	.	.	1	41	63	5	.	.	.	.	110
5.00 - 5.99	.	.	.	1	17	8	.	.	.	.	26
6.00 - 6.99	.	.	.	.	2	1	.	.	.	.	3
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	21512	14337	10755	8155	3275	382	19	0	0	5	58440

STATION: 99

OCCURRENCES OF WIND SPEED BY MONTH FOR ALL YEARS

WS(m/sec)	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
0.00 - 2.49	123	129	142	197	237	242	248	346	280	179	141	144	2408
2.50 - 4.99	1091	1147	1296	1800	2372	2433	2845	2739	2366	1815	1420	1231	22555
5.00 - 7.49	995	932	1054	1230	1424	1394	1328	1382	1234	1328	1071	907	14279
7.50 - 9.99	1093	1136	1384	1091	838	690	531	459	775	1079	1036	1007	11119
10.00 - 12.49	745	573	618	316	65	38	8	33	111	367	584	692	4150
12.50 - 14.99	649	437	347	142	18	3	.	1	33	162	438	691	2921
15.00 - 17.49	113	88	60	21	6	.	.	.	1	24	66	149	528
17.50 - 19.99	104	66	55	2	.	.	.	.	.	3	33	115	378
20.00 - GREATER	47	12	4	1	.	.	.	.	.	3	11	24	102
TOTAL	4960	4520	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960	58440

(Sheet 3 of 5)

Table A2 (Continued)

WIS ATLANTIC REVISION 1956 - 1975
LAT: 43.50 N, LONG: 70.25 W, DEPTH: 18 M

STATION: 99

OCCURRENCES OF WIND DIRECTION BY MONTH FOR ALL YEARS

WD(deg) DIRECTION BAND & CENTER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
337.50 - 22.49 (0.0)	678	560	688	645	380	288	220	345	476	509	535	677	6001
22.50 - 67.49 (45.0)	305	340	406	245	243	161	77	184	274	327	361	362	3285
67.50 - 112.49 (90.0)	224	303	337	228	192	150	80	78	256	262	265	369	2744
112.50 - 157.49 (135.0)	268	358	431	391	457	285	172	242	368	322	367	381	4042
157.50 - 202.49 (180.0)	423	355	468	620	762	816	733	569	615	639	761	519	7280
202.50 - 247.49 (225.0)	636	446	422	663	1046	1361	1562	1358	932	922	661	593	10602
247.50 - 292.49 (270.0)	1064	875	816	992	1085	1120	1435	1373	1007	1065	952	854	12638
292.50 - 337.49 (315.0)	1362	1283	1392	1016	795	619	681	811	872	914	898	1205	11848
TOTAL	4960	4520	4960	4800	4960	4800	4960	4960	4800	4960	4800	4960	58440

STATION: 99

SUMMARY OF MEAN Hmo(m) BY MONTH AND YEAR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1956	1.74	0.99	1.01	0.82	0.70	0.70	0.64	0.63	0.66	0.79	1.00	1.09	0.90
1957	1.09	0.88	0.95	0.93	0.59	0.67	0.57	0.51	0.68	0.84	1.10	1.38	0.85
1958	1.55	1.14	1.20	1.30	0.88	0.81	0.57	0.68	0.79	1.05	1.13	1.01	1.01
1959	1.32	1.04	1.16	0.78	0.60	0.62	0.68	0.58	0.61	1.06	1.19	1.19	0.90
1960	1.06	1.37	1.18	0.79	0.77	0.76	0.62	0.47	0.72	0.94	1.08	1.16	0.91
1961	1.20	0.96	1.03	0.86	0.86	0.67	0.54	0.50	0.84	1.06	1.07	1.14	0.89
1962	1.17	1.04	1.26	0.92	0.75	0.59	0.58	0.73	0.85	1.02	1.17	1.31	0.95
1963	1.05	1.12	1.13	0.92	0.88	0.57	0.61	0.57	0.85	0.87	1.48	1.14	0.93
1964	1.45	1.28	1.19	0.85	0.87	0.77	0.69	0.71	0.85	0.84	1.06	1.30	0.99
1965	1.36	1.25	0.87	0.79	0.62	0.74	0.62	0.76	0.74	1.08	1.14	1.05	0.92
1966	1.54	1.01	0.98	0.59	0.75	0.67	0.69	0.58	0.86	0.91	1.18	1.28	0.92
1967	1.20	1.31	0.96	1.16	0.97	0.72	0.64	0.59	0.91	0.96	1.16	1.48	1.00
1968	1.37	1.17	1.32	1.06	0.70	0.74	0.65	0.66	0.61	0.97	1.26	1.46	1.00
1969	1.23	1.60	1.26	1.00	0.99	0.78	0.78	0.72	0.79	0.91	1.41	1.63	1.09
1970	0.98	1.38	0.96	0.93	0.94	0.82	0.72	0.71	0.68	0.92	1.13	1.43	0.96
1971	1.14	1.28	1.17	0.89	0.81	0.68	0.69	0.73	0.77	0.83	1.08	1.23	0.94
1972	1.10	1.31	1.18	0.77	1.03	1.01	0.56	0.66	0.91	0.96	1.07	1.24	0.98
1973	1.36	1.18	1.18	1.25	0.86	0.79	0.81	0.58	0.84	0.98	1.15	1.52	1.04
1974	0.96	1.11	1.31	1.08	0.82	0.79	0.64	0.63	0.80	0.96	1.24	1.36	0.97
1975	1.31	1.00	1.24	1.04	0.69	0.85	0.86	0.60	0.85	0.90	1.21	1.67	1.02
MEAN	1.26	1.17	1.13	0.94	0.80	0.74	0.66	0.63	0.78	0.94	1.17	1.30	

STATION: 99

MAX Hmo(m)*10 WITH ASSOCIATED Tp(sec) AND Dp(deg/10) BY MONTH AND YEAR

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MAX
1956	541310	37 818	37 910	28 7 9	18 616	15 619	17 619	19 913	18 619	22 715	37 818	35 817	541310
1957	26 710	22 914	32 8 9	26 814	15 523	27 716	17 618	12 520	18 718	17 617	31 817	34 816	34 816
1958	401012	411012	501112	311113	22 914	19 618	15 516	19 615	21 621	22 7 9	27 717	25 722	501112
1959	34 731	24 631	41 912	19 716	15 619	15 618	16 714	16 520	16 620	501214	35 816	40 910	501214
1960	33 818	431012	421112	22 718	16 913	19 714	17 618	15 619	21 814	21 8 9	34 818	331013	431012
1961	371214	43 911	341012	24 7 9	271014	16 520	14 523	16 521	321014	25 9 9	28 810	37 917	43 911
1962	32 816	27 7 9	381314	23 710	19 616	15 521	13 427	17 8 9	26 7 9	29 812	30 818	481212	481212
1963	29 631	26 630	29 817	22 716	24 714	15 618	14 618	16 616	20 913	30 634	531112	33 814	531112
1964	391113	29 633	31 816	22 716	17 620	21 619	16 519	24 716	29 719	21 620	351014	33 731	391113
1965	30 812	581114	19 530	20 715	15 618	17 619	20 718	17 619	23 718	32 817	31 818	27 717	581114
1966	501112	32 912	24 625	15 617	16 519	15 521	16 521	15 524	22 622	25 718	431114	28 715	501112
1967	431012	29 719	21 5 2	331313	291011	19 5 8	15 521	17 619	23 715	31 817	30 818	41 9 9	431012
1968	33 731	311113	361012	29 719	20 619	18 712	20 719	24 719	17 714	28 818	421111	30 813	421111
1969	32 627	531212	371012	30 818	27 717	17 618	19 716	17 619	20 619	22 718	32 816	631213	631213
1970	33 818	37 818	29 716	25 914	27 719	19 718	22 718	19 914	18 618	26 913	34 816	481213	481213
1971	34 817	32 814	40 8 9	231015	19 713	16 521	21 618	17 620	17 619	19 621	441012	34 818	441012
1972	28 719	391010	27 914	17 531	20 911	30 912	20 718	16 524	371113	27 719	33 912	32 810	391010
1973	28 7 7	351016	25 714	421013	24 717	19 715	20 719	13 522	25 719	31 911	27 816	351013	421013
1974	31 817	27 717	32 815	27 7 8	25 719	22 718	16 521	22 719	27 718	34 818	331214	541113	541113
1975	37 918	34 816	37 916	42 914	21 5 3	22 718	211214	14 522	25 719	18 812	34 819	601312	601312
MAX	541310	581114	501112	42 914	291011	30 912	22 718	24 719	371113	501214	531112	631213	

MAX Hmo(m): 6.3 MAX Tp(sec): 12. MAX Dp(deg): 130. DATE(gmt): 69122706

MAX WIND SPEED(m/sec): 25. MAX WIND DIRECTION(deg): 275. DATE(gmt): 69010206

(Sheet 4 of 5)

Table A2 (Concluded)

WIS ATLANTIC REVISION 1956 - 1975
LAT: 43.50 N, LONG: 70.25 W, DEPTH: 18 M
OCCURRENCES OF WAVE HEIGHT AND PEAK PERIOD FOR 45-DEG DIRECTION BANDS

STATION: 99 (45.00 - 89.99) 67.5 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	581	161	24	.	.	.	.	.	.	.	766
1.00 - 1.99	180	307	45	5	.	.	.	.	.	.	537
2.00 - 2.99	.	70	31	14	.	.	.	.	.	.	115
3.00 - 3.99	.	3	12	.	.	.	.	.	.	.	15
4.00 - 4.99	.	.	.	1	.	.	.	.	.	.	1
5.00 - 5.99	.	.	.	.	.	.	.	.	.	.	0
6.00 - 6.99	.	.	.	.	.	.	.	.	.	.	0
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	761	541	112	20	0	0	0	0	0	0	1434

STATION: 99 (90.00 - 134.99) 112.5 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	1274	1531	5436	4327	1672	170	4	.	.	.	14414
1.00 - 1.99	118	1266	1537	1635	692	88	4	.	.	.	5340
2.00 - 2.99	.	121	508	557	265	29	8	.	.	.	1488
3.00 - 3.99	.	.	69	190	112	25	3	.	.	.	399
4.00 - 4.99	.	.	1	40	60	5	.	.	.	.	106
5.00 - 5.99	.	.	.	1	17	8	.	.	.	.	26
6.00 - 6.99	.	.	.	.	2	1	.	.	.	.	3
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	1392	2918	7551	6750	2820	326	19	0	0	0	21776

STATION: 99 (80.50 - 125.49) 103.0 DEG

Hmo(m)	Tp(sec) 3.0-4.9	5.0-6.9	7.0-8.9	9.0-10.9	11.0-12.9	13.0-14.9	15.0-16.9	17.0-18.9	19.0-20.9	21.0-LONGER	TOTAL
0.00 - 0.99	724	539	831	1149	653	48	.	.	.	.	3944
1.00 - 1.99	80	791	453	342	160	18	.	.	.	.	1844
2.00 - 2.99	.	96	295	140	33	4	6	.	.	.	574
3.00 - 3.99	.	.	58	99	22	1	.	.	.	.	180
4.00 - 4.99	.	.	1	29	30	2	.	.	.	.	62
5.00 - 5.99	.	.	.	.	12	5	.	.	.	.	17
6.00 - 6.99	.	.	.	.	1	1	.	.	.	.	2
7.00 - 7.99	.	.	.	.	.	.	.	.	.	.	0
8.00 - 8.99	.	.	.	.	.	.	.	.	.	.	0
9.00 - GREATER	.	.	.	.	.	.	.	.	.	.	0
TOTAL	804	1426	1638	1759	911	79	6	0	0	0	6623

STATION: 99

OCCURRENCES OF WIND DIRECTION BY MONTH FOR ALL YEARS

WD(deg) DIRECTION BAND & CENTER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
45.00 - 89.99 (67.5)	262	296	379	240	218	176	74	117	282	324	346	381	3095
90.00 - 134.99 (112.5)	306	424	473	386	409	254	162	197	404	386	374	475	4250
80.50 - 125.49 (103.0)	500	651	653	550	658	179	214	316	777	606	679	791	6574

(Sheet 5 of 5)

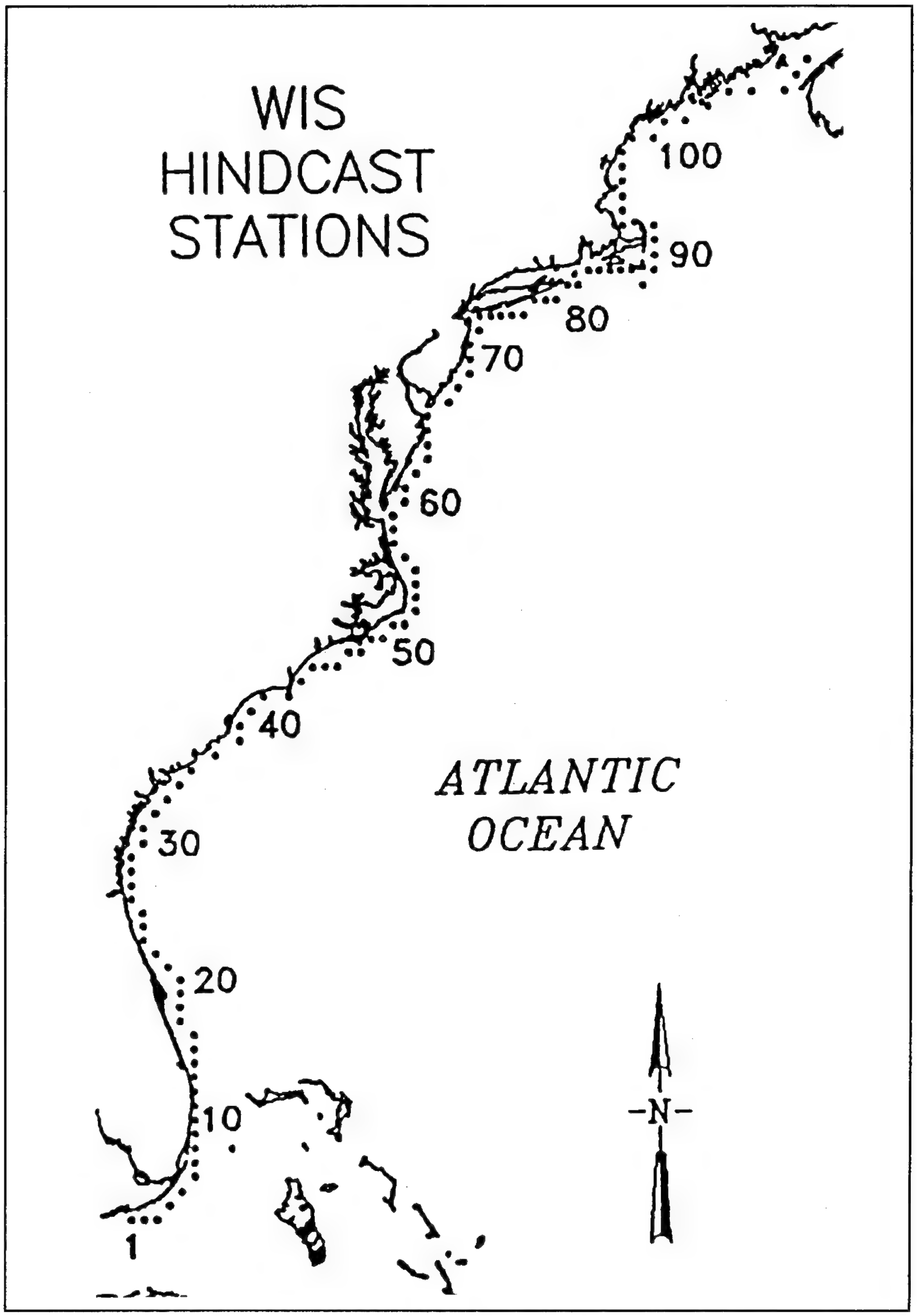


Figure A2. Wave information study (WIS) hindcast stations

against buoy data. In such cases, WIS figures may either represent the mean wave direction or the peak mean wave direction associated with the largest energy (Hubertz et al. 1993). In this study, the WIS directions used for numerical modeling input represented the mean wave direction.

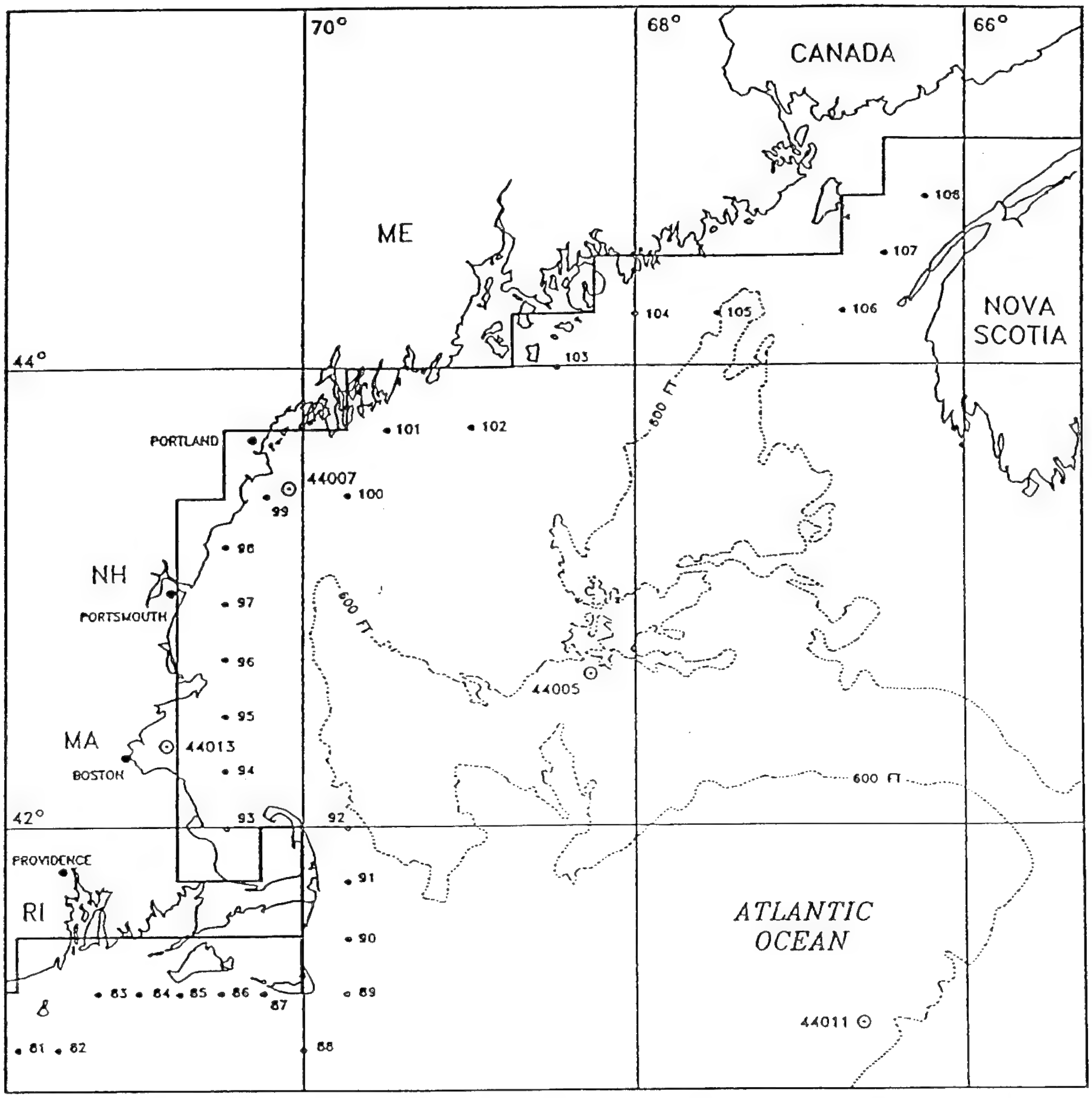


Figure A3. Location of WIS stations (solid dots), NOAA buoys (circled dots), land/water boundary (solid thin line, actual; solid wide line, model), and continental shelf boundary (dotted line)

Details of the WIS North Atlantic hindcast are provided elsewhere, and thus, only a brief overview of the WIS analysis is given here for completeness. Completed WIS hindcast estimates for U.S. coastal waters were performed in three phases. Phases I and II, respectively, provided wind and wave conditions in deep water and over the continental shelf region. Phase III determined wave conditions at the 10-m (33-ft) depth. The original WIS hindcast for the Atlantic Coast Phase II included stations outside the Saco Bay area (Corson et al. 1981). Phase III hindcast for the Atlantic Coast had a station within Saco Bay (Jensen 1983), but wave data were generated by transforming Phase II results to a depth of 10 m (33 ft) assuming straight and parallel

bottom contours. No additional energy sources, such as winds, were added to the existing Phase II wave conditions. Therefore, the simplified transformation of waves from deep water to shallow water used during Phase III, was considered to be inadequate for this project. Revised North Atlantic hindcast data (Hubertz et al. 1993) have recently been developed using the latest wave and wind models. This new WIS hindcast provides more reliable data which supersede all information contained in previous WIS Reports, and was, therefore, used in the numerical modeling task for the Saco Bay project.

Procedures to produce revised WIS information and examples of verification against measurements are described elsewhere (Hubertz et al. 1993). The revised 20-year U.S. Atlantic Coast WIS hindcast of wind and wave information provides wave height, period, direction, and wind speed and direction at 3-hr intervals. These data are summarized for 108 stations along the U.S. Atlantic Coast and for 3 stations along the north coast of Puerto Rico. The revised hindcast gives summary tables for occurrences (by month) of spectral wave height, peak period, peak mean wave direction, wind speed, and wind direction for categories of 0.5 m (1.6 ft) 1.0 s, 22.5 deg, 2.5 m/s (8.2 fps), and 45.0 deg, respectively. An example summary table for station 99 in Saco Bay is provided in Table A2. In addition, for each station, joint occurrences of height and period for 45-deg direction bands and all directions are presented. Finally, mean heights by month and year and maximum heights by month and year, with associated peak periods and peak mean wave directions are provided for each station. The 20-year time series of wind and wave information, including spectra at each station, are also available from the WIS archives as one-line records every 3 hr.

Numerical Model Selection

A time-independent spectral model called STWAVE was also considered for simulating the nearshore wave transformation in the Saco Bay. Since STWAVE does not have the capability to diffract waves around features such as the Cape Elizabeth, High Head, Richmond Island, Prouts Neck, and several other islands present inside the Saco Bay Sound, and given that these features can significantly influence wave energy in the vicinity of the Saco River mouth, it was necessary to consider a different model. The numerical model REFDIF, a combined refraction-diffraction model, was therefore considered to be better suited for this study, and was selected to transform waves within Saco Bay. This model is suitable especially for varying bathymetry in domains which include islands and are surrounded by complex land boundaries. Features of this model will be described later in this section.

Modeling Issues, Procedures, and Input

The modeling domain was extended 3.2 km (2 miles) offshore from WIS station 99. This was done for considering possible land-boundary effects from

High Head Peninsula and Richmond Island, both situated in the northeast side of the modeling area, since diffraction and sheltering effects from land boundaries and bathymetry were not included in the WIS hindcast. By positioning the offshore edge of the modeling region beyond WIS station 99, combined effects of diffraction, refraction, and shoaling will properly be modelled by REFDIF, especially for waves entering Saco Bay from the northeast or the straight in east directions.

The bathymetry for Saco Bay was digitized from NOAA chart 13287 (1:20,000 scale), dated April 11, 1981. Data from bathymetric surveys were later incorporated to supplement the chart information. This included surveying data for the area north of the north jetty. Boundaries of the modeling domain covered a rectangle 21.8 × 19.4 sq km (8.4 × 7.5 square miles) in size, with the following coordinates: southwest corner (70° 24′ W, 43° 26.2′ N), southeast corner (70° 12.5′ W, 43° 26.2′ N), northwest corner (70° 24′ W, 43° 33.7′ N), and northeast corner (70° 12.5′ W, 43°33.7′ N). Between 70° 20′ W and 70° 18′ W, the nearshore bathymetry was digitized using each depth sounding value available from the NOAA chart. Large and small islands present inside this sub-region, including Basket Island, Stage Island, Negro Island, Wood Island, Gooseberry Island, Ram Island, Bluff Island, and Stratton Island were defined as land boundaries in the input bathymetry file. The Prouts Neck to north side extruding into the area of interest was also discretized in the input data. From 70° 18′ W to the deepwater offshore edge of the modeling region, bathymetry was digitized using every other depth value from the chart. Length scales for the x- and y-axes of NOAA chart 13287 are 1.17 and 1.6 km (0.73 and 1.00 mile) per minute of longitude and latitude, respectively. On-offshore extent of the model domain was 15,545 km (51,000 ft) and alongshore extent of the model domain was 14,020 m (46,000 ft).

Next, the REFDIF model parameters related to the size of the modeling area were determined. Grid spacing of 152 m (500 ft) ($\Delta x = \Delta y = 500.0$ ft) in the x- and y-directions was used. These grid spacings are adequate for wave modeling transformation in the Saco Bay for the range of wave periods listed in Tables A1 and A2. The total number of nodes in the x- and y-directions are 102 and 91, based on these grid sizes. However, to ensure computational accuracy of the numerical model predictions, these 152-m (500-ft) nodal spacings were further divided into finer increments in the x- and y-directions by specifying certain model input parameters. Actual computations in the REFDIF model were made with grids ranging from 3 to 7.6 m (10 to 25 ft), depending on wave periods. This model requires six or more grid points per wavelength, and its predictions improve if this condition is met. In terms of computing and storage needs, this requirement may force running the model on large and fast computer platforms for large domains. The CRAY Y-MP computer was used in this study.

With the exception of digitizing the NOAA chart with the AUTOCAD program, all numerical modeling tasks of this study were performed on the CRAY Y-MP computer. Interface software was developed and tested for

transforming the digitized data from latitude and longitude coordinates into the engineering (lineal) distances in feet. To obtain depth data at nodal points, interpolation and smoothing schemes were applied to the digitized bathymetry data using three-dimensional surface contour mapping.

Output

Wave estimates by numerical model were made over the entire rectangular computational domain. The grid origin was located in the northeast corner of the model area with the x-axis pointing toward the coastline in the east-west direction, and the y-axis nearly paralleling the north-south direction. As stated earlier, numerical model results were output at a transect specified by the physical model study task personnel. This output location is denoted by TR 3 and labelled on Figure A1, together with five other transects. TR 3 is oriented approximately -60 deg to the grid setup, clockwise from the x-axis. Assuming that some comparison of the physical model study with numerical model predictions may later be desirable, five other transects (TR 1, TR 2, TR 5, TR 6, and TR 7) were selected for additional output. These transects are located just north of the north jetty where erosion problems have been observed.

A nodal point in the x-y two-dimensional grid space may be specified as P(I,J), where I and J are the grid node or cell numbers in the x- and y-directions, respectively. A line drawn over a grid hereafter called a transect may either pass exactly through these grid points or be near them. The output along a transect may therefore represent values at the nodal points or it may correspond to the nearest neighboring nodes. Transect output may also correspond to some average or interpolated value for several grid points assumed to represent a given transect. The list output for TR 3, approximately where the wave generator is situated, includes all 25 nodal points on or close to the transect line from start to end. Example plots, on the other hand, show model predictions for TR 3 for 10 nodal points on this transect. In summary, when interpreting numerical model output, it is important to recognize that TR 3 is arbitrary, and that points selected at equal intervals or randomly on this transect may not necessarily coincide with the actual grid points. This is not the case for TR 1 and 2, which are along the x-axis (i.e., y=constant or J=constant), and their output will therefore be at the nodal points. Likewise, the output for TR 5, 6, and 7, which are along the y-axis (i.e., x=constant or I=constant), is also at the actual nodal points.

Description of Numerical Model REFDIF

REFDIF is a combined refraction/diffraction model based on Booji's (1981) weak current parabolic approximation for Berkhoff's (1973) mild slope equation, where backward reflected waves are neglected, but forward reflected waves are considered. Kirby and Dalrymple (1983a,b, and 1986a,b), Liu and Tsay (1984), Kirby (1984 and 1986), Dalrymple (1988 and 1991), and

Dalrymple et al. (1984a,b) presented the corrected form of the mild slope equation including the influence of strong currents, wave amplitude nonlinearities, and islands/structures. This model is valid for waves propagating within the ±70-deg sector to the principal assumed wave direction used for input. The mild slope equation, in terms of the horizontal gradient operator, is given by

$$\nabla \cdot CC_g \nabla A + \sigma^2 \frac{C_g}{C} A = 0 \qquad \text{(A1)}$$

where

C = wave celerity

C_g = group velocity

A = wave amplitude

σ = angular frequency

and the linear dispersion relationship is

$$\sigma^2 = gk \tanh kh \qquad \text{(A2)}$$

where

g = gravitational constant

k = wave number

h = water depth

The model is based on Stokes' perturbation expansion. In order to have a model that is valid in shallow water outside the Stokes range of validity, a dispersion relationship which accounts for the nonlinear effects of amplitude is included in REFDIF. This relationship, developed by Hedges (1976), is

$$\sigma^2 = gk \tanh(kh(1 + |A|/h)) \qquad \text{(A3)}$$

The Hedges form is coupled to the Stokes relationship to form a hybrid model valid in shallow and deep water. The model can be operated in three different modes: (a) linear, (b) Stokes-to-Hedges nonlinear, and (c) Stokes weakly nonlinear. The linear mode was used in this study since wave breaking along TR 3 (wave generator location) was not of concern. Model predictions

confirm this expectation. Since wave breaking was not considered, unit wave amplitudes were used in the input to the model REFDIF. For simulating effects of water level conditions during extreme storm events, a tidal datum was specified in the model input.

In applications where wave breaking is important, the model REFDIF should be used in a nonlinear mode. The wave breaking scheme in REFDIF is based on Kirby and Dalrymple's (1986a,b) dissipation scheme; that is,

$$D_f = \frac{KC_g(1-(\gamma h/H)^2)}{h} \tag{A4}$$

where

D_f = dissipation factor

$K\gamma$ = empirical constant determined by Dally et al. (1985)

H = wave height

h = water depth

Wave breaking is initiated using the breaking index; that is, $H > 0.78\ h$. If wave height exceeds 0.78 h, the wave breaking scheme is activated and wave amplitude is reduced based on Equation A4.

Land boundaries such as coastlines and islands are modeled using the thin film approach. Surface-piercing structures or other similar features may be modeled as shoals with very shallow depth, less than 0.1 m (0.03 ft). Earlier applications of REFDIF may be found in Kirby and Dalrymple (1986a,b) and Dalrymple et al. (1984a,b). Recent Corps applications of REFDIF include the Revere Beach, San Juan navigational channel, Kings Bay, Chignik and Sitka Harbors, and Indian River Inlet, and Fire Island projects.

Note that although REFDIF is a monochromatic wave model (i.e., it is a model based on mass balance and founded on the mild-slope equation), it is possible to consider transformation of spectral waves with this model. This may be done by superposition of individual linear monochromatic waves. This approach requires a large number of model runs to represent many frequency and direction bands. Spectral representation becomes less important when wave frequency and direction spectra are narrow. Coastal waves far from the influence of wave energy growth mechanisms typically exhibit a narrow spectral character, an indication that discrete frequency analysis may suffice for engineering estimates. A spectral version of the REFDIF model presently in development was not ready for this study.

Results and Discussion

Using input data (Table A1) derived from the 20-year WIS hindcast (Table A2) and a 102 × 91 grid, the wave model REFDIF generated wave characteristics within the Saco Bay grid. Square cells (152 m or 500 ft) on each side) were chosen in order to resolve bathymetric features in Saco Bay. Figure A1 shows a portion of the REFDIF grid for the immediate area of interest extending beyond the physical model study boundaries. Some of the most prominent land features, the transects where model results were saved, and the two jetties in the Saco River mouth, are depicted in Figure A1.

The input boundary of the REFDIF model grid is along the first row (offshore row along the y-axis), and is situated at about the 61-m (200-ft) water depth. The origin (cell (1,1)) is located at the northeast corner of the model domain in such a way that the x-axis is directed nearly due west (pointing from offshore-to-shore) and the y-axis points almost due south. North is nearly in the negative y direction. The overall REFDIF grid covered an area much larger than the physical model study area in order to ensure that diffractive and sheltering effects due to land masses and bathymetry were adequately modeled as well as to move any side boundary effects out of the study area. For other details about model setup, consult "Modeling Issues, Procedures, and Input," above.

Three different analyses were used for the nearshore wave estimates in Saco Bay. These included REFDIF numerical model predictions, refraction and shoaling, and Snell's law estimates based on the linear wave theory for which a model was specifically developed for this study, and smoothed REFDIF predictions representing average results along the transects described earlier. Snell law estimates based on linear theory were provided because physical model study personnel specifically requested information about the shoaling and refraction coefficients in addition to the REFDIF model estimates. Since it is not possible to separate shoaling and refraction from the predictions of the REFDIF model, it was decided to develop a separate computer program to generate these coefficients. For this purpose, linear wave theory was used for computation of parameters for Snell's law formulas. Wave number was calculated by the Pade approximation of the linear dispersion relation (Hunt 1979). Actual wave condition (height, period, and direction) values in Table A1 were also used in this method.

Two tidal datum values were considered; a 0.0-ft tidal datum corresponding to mean low water (mlw), and a +2.7-m (+8.8-ft) tidal datum for mean high water (mhw) level. For the mhw case, input wave conditions (Table A1) were expanded to include more wave periods (9 and 11 sec for the 45-deg incident wave direction, and 3 and 13 sec for the 22.5-deg incident wave direction, respectively). These additions were mainly for the northeasterly storm, which may reach the wave generator location (in the physical model setup) since wave energy may increase with an increase in water level (i.e., from 0.0 to

+2.7 m (0.0 to +8.8 ft)). Typical output examples presented in this report are based on mlw datum.

The REFDIF model was used in the linear mode with unit-amplitude waves for all input conditions (Table A1) to transform waves from the deepwater offshore boundary to the study area. Wave estimates for two historical storms, the Blizzard of 1978 and the Halloween 1991 storm, were also simulated. For each of these historical storms, four wave periods and associated directions, selected from the WIS analysis, were used. Tidal datums of +4.1 and +3.7 m (+13.6 and +12.0 ft), respectively, were used for the Blizzard of 1978 and the Halloween 1991 storms. Numerical predictions were categorized for incident wave angles of 0 deg, ±22.5 deg, ±45.0 deg, and -13.0 deg. Estimates for incident wave angles of ±22.5 deg and ±45.0 deg were grouped as a set. Results were presented both in tables and plots for the six transects described above. The structure of output information is the same for all categories and is briefly described next.

An example of tabular output data for 11-sec waves from 0 deg is presented in Table A3 for TR 1-3. Output shown in the table starts with model predictions, followed by Snell's law estimates. Snell's law computations were made only for shoaling and refraction coefficients requested for the physical model study. The other computed quantities listed in the Snell's law tables are included for comparing model versus linear theory. This revealing comparison shows the order of magnitude of errors involved with the use of a simplified wave transformation/propagation analysis. This tabular output was completed for all six transects for the same input wave condition.

The tabular output is self-explanatory, since column headings indicate the quantity being listed. The first three lines in the tables are general information, indicating that predictions are obtained either by the REFDIF model or by linear wave theory. Printed next are the wave condition identifier (unchanged), wave amplitude, incident wave direction, wave period, and transect number. Headings for eight columns indicate what is printed under each column. These include the I and J grid numbers, depth, computed amplitude and direction, period, transect number, and wave-breaking index. The convention for wave direction is that angles are positive counterclockwise from the positive x axis and negative clockwise from the x axis.

Wave height (=2.0 * amplitude) and water depth information listed in the tables is also displayed by line plots. An example is shown in Figure A4 for 5-sec waves from 0 deg for TR 3. Wave heights were plotted on positive y-axis versus nodal points (grid numbers) on the x-axis. Depth values corresponding to the same grid points were also plotted on the negative y-axis using a grid spacing of 152 m (500 ft). Depths were scaled (divided by 10) for convenience of graphical output and wave heights were multiplied by 10 to amplify small values resulting from computations.

Analysis of REFDIF model results indicates that offshore waves arriving at the neighborhood of the Saco River mouth can be greatly amplified. Wave

Table A3
Example of Tabular Output Data

REFDIF MODEL PREDICTIONS

INPUT CASE = # 1 AMP = 1.0 DIR = 0.0 PERIOD = 11.0 TRANSECT # = 3

I	J	DEPTH	AMPLITUDE	DIRECTION	PERIOD	TRANSECT #	BRK INI
81	75	9.1	1.1	-51.3	11.0	3	0
81	74	9.3	0.9	-38.3	11.0	3	0
82	73	23.8	0.5	-19.4	11.0	3	0
82	72	43.6	0.8	-24.9	11.0	3	0
82	71	40.2	1.0	-39.7	11.0	3	0
83	70	50.3	0.9	-19.7	11.0	3	0
83	69	41.0	1.7	-54.2	11.0	3	0
83	68	45.1	1.4	-74.1	11.0	3	0
84	67	37.9	1.8	-47.6	11.0	3	0
84	66	40.9	1.1	-55.8	11.0	3	0
85	65	35.8	0.9	-64.3	11.0	3	0
85	64	35.5	1.1	-18.6	11.0	3	0
85	63	49.6	1.2	-14.0	11.0	3	0
86	62	43.4	0.3	13.9	11.0	3	0
86	61	55.7	0.3	3.0	11.0	3	0
87	60	44.0	0.5	25.3	11.0	3	0
87	59	49.0	1.6	-3.5	11.0	3	0
87	58	52.6	1.3	2.1	11.0	3	0
88	57	34.7	2.1	2.6	11.0	3	0
88	56	53.8	1.9	4.3	11.0	3	0
88	55	54.1	0.6	-4.0	11.0	3	0
89	54	57.8	0.1	-25.9	11.0	3	0
89	53	58.8	0.7	-18.3	11.0	3	0
89	52	59.7	0.2	-63.3	11.0	3	0
90	51	56.7	0.6	-12.9	11.0	3	0

AVERAGE AMP = 1.0 AVERAGE DIRECTION = -23.9

REFRACTION AND SHOALING BASED PREDICTIONS (LINEAR THEORY)

I	J	AMPO	DIRO	PERO	DEP	AMP	DIR	IBR	KS	KR
81	75	1.0	0.0	11.0	9.1	1.3	0.0	0	1.31	1.00
81	74	1.0	0.0	11.0	9.3	1.3	0.0	0	1.31	1.00
82	73	1.0	0.0	11.0	23.8	1.1	0.0	0	1.07	1.00
82	72	1.0	0.0	11.0	43.6	1.0	0.0	0	0.97	1.00
82	71	1.0	0.0	11.0	40.2	1.0	0.0	0	0.98	1.00
83	70	1.0	0.0	11.0	50.3	1.0	0.0	0	0.95	1.00
83	69	1.0	0.0	11.0	41.0	1.0	0.0	0	0.98	1.00
83	68	1.0	0.0	11.0	45.1	1.0	0.0	0	0.97	1.00
84	67	1.0	0.0	11.0	37.9	1.0	0.0	0	0.99	1.00
84	66	1.0	0.0	11.0	40.9	1.0	0.0	0	0.98	1.00
85	65	1.0	0.0	11.0	35.8	1.0	0.0	0	1.00	1.00
85	64	1.0	0.0	11.0	35.5	1.0	0.0	0	1.00	1.00
85	63	1.0	0.0	11.0	49.6	1.0	0.0	0	0.95	1.00
86	62	1.0	0.0	11.0	43.4	1.0	0.0	0	0.97	1.00
86	61	1.0	0.0	11.0	55.7	0.9	0.0	0	0.94	1.00
87	60	1.0	0.0	11.0	44.0	1.0	0.0	0	0.97	1.00
87	59	1.0	0.0	11.0	49.0	1.0	0.0	0	0.96	1.00
87	58	1.0	0.0	11.0	52.6	0.9	0.0	0	0.95	1.00
88	57	1.0	0.0	11.0	34.7	1.0	0.0	0	1.00	1.00
88	56	1.0	0.0	11.0	53.8	0.9	0.0	0	0.95	1.00
88	55	1.0	0.0	11.0	54.1	0.9	0.0	0	0.95	1.00
89	54	1.0	0.0	11.0	57.8	0.9	0.0	0	0.94	1.00
89	53	1.0	0.0	11.0	58.8	0.9	0.0	0	0.94	1.00
89	52	1.0	0.0	11.0	59.7	0.9	0.0	0	0.94	1.00
90	51	1.0	0.0	11.0	56.7	0.9	0.0	0	0.94	1.00

AVERAGE AMP = 1.0 AVERAGE DIRECTION = 0.0

(Sheet 1 of 3)

Table A3 (Continued)

RESULTS SMOOTHED BY INTERPOLATION

I	J	DEPTH	AMPLITUDE	DIRECTION	PERIOD	TRANSECT #	BRK IND
81	75	9.1	1.1	16.1	11.0	3	0
81	74	9.3	0.9	-7.1	11.0	3	0
82	73	23.8	0.5	-11.9	11.0	3	0
82	72	43.6	0.8	6.9	11.0	3	0
82	71	40.2	1.0	5.3	11.0	3	0
83	70	50.3	0.9	-12.9	11.0	3	0
83	69	41.0	1.7	5.4	11.0	3	0
83	68	45.1	1.4	5.3	11.0	3	0
84	67	37.9	1.8	-5.6	11.0	3	0
84	66	40.9	1.1	5.0	11.0	3	0
85	65	35.8	0.9	5.0	11.0	3	0
85	64	35.5	1.1	-11.8	11.0	3	0
85	63	49.6	1.2	-14.0	11.0	3	0
86	62	43.4	0.3	-13.9	11.0	3	0
86	61	55.7	0.3	3.0	11.0	3	0
87	60	44.0	0.5	6.1	11.0	3	0
87	59	49.0	1.6	-3.5	11.0	3	0
87	58	52.6	1.3	2.1	11.0	3	0
88	57	34.7	1.8	2.6	11.0	3	0
88	56	53.8	1.9	4.3	11.0	3	0
88	55	54.1	0.6	-4.0	11.0	3	0
89	54	57.8	0.5	-13.0	11.0	3	0
89	53	58.8	0.7	13.4	11.0	3	0
89	52	59.7	0.5	-5.0	11.0	3	0
90	51	56.7	0.6	12.9	11.0	3	0

AVERAGE AMP = 1.0 AVERAGE DIRECTION = -0.4

REFDIF MODEL PREDICTIONS

INPUT CASE = # 1 AMP = 1.0 DIR = 0.0 PERIOD = 11.0 TRANSECT # = 2

I	J	DEPTH	AMPLITUDE	DIRECTION	PERIOD	TRANSECT #	BRK IND
96	70	14.9	1.5	45.3	11.0	2	0
97	70	13.9	0.2	89.8	11.0	2	0
98	70	12.9	1.4	45.6	11.0	2	0
99	70	12.8	2.9	81.2	11.0	2	0
100	70	12.8	0.2	16.3	11.0	2	0

AVERAGE AMP = 1.2 AVERAGE DIRECTION = 55.6

REFRACTION AND SHOALING BASED PREDICTIONS (LINEAR THEORY)

I	J	AMP0	DIR0	PER0	DEP	AMP	DIR	IBR	KS	KR
96	70	1.0	0.0	11.0	14.9	1.2	0.0	0	1.18	1.00
97	70	1.0	0.0	11.0	13.9	1.2	0.0	0	1.20	1.00
98	70	1.0	0.0	11.0	12.9	1.2	0.0	0	1.22	1.00
99	70	1.0	0.0	11.0	12.8	1.2	0.0	0	1.22	1.00
100	70	1.0	0.0	11.0	12.8	1.2	0.0	0	1.22	1.00

AVERAGE AMP = 1.2 AVERAGE DIRECTION = 0.0

RESULTS SMOOTHED BY INTERPOLATION

I	J	DEPTH	AMPLITUDE	DIRECTION	PERIOD	TRANSECT #	BRK IND
96	70	14.9	1.5	4.4	11.0	2	0
97	70	13.9	1.0	5.2	11.0	2	0
98	70	12.9	1.4	5.5	11.0	2	0
99	70	12.8	1.8	5.3	11.0	2	0
100	70	12.8	1.1	10.9	11.0	2	0

AVERAGE AMP = 1.4 AVERAGE DIRECTION = 6.3

(Sheet 2 of 3)

Table A3 (Concluded)

REFDIF MODEL PREDICTIONS

INPUT CASE = # 1 AMP = 1.0 DIR = 0.0 PERIOD = 11.0 TRANSECT # = 1

I	J	DEPTH	AMPLITUDE	DIRECTION	PERIOD	TRANSECT #	BRK IND
100	68	13.9	1.3	37.5	11.0	1	0
101	68	13.8	0.8	47.8	11.0	1	0
102	68	12.8	0.4	24.1	11.0	1	0

AVERAGE AMP = 0.8 AVERAGE DIRECTION = 36.5

REFRACTION AND SHOALING BASED PREDICTIONS (LINEAR THEORY)

I	J	AMP0	DIR0	PER0	DEP	AMP	DIR	IBR	KS	KR
100	68	1.0	0.0	11.0	13.9	1.2	0.0	0	1.20	1.00
101	68	1.0	0.0	11.0	13.8	1.2	0.0	0	1.20	1.00
102	68	1.0	0.0	11.0	12.8	1.2	0.0	0	1.22	1.00

AVERAGE AMP = 1.2 AVERAGE DIRECTION = 0.0

RESULTS SMOOTHED BY INTERPOLATION

I	J	DEPTH	AMPLITUDE	DIRECTION	PERIOD	TRANSECT #	BRK IND
100	68	13.9	1.3	5.3	11.0	1	0
101	68	13.8	0.8	5.6	11.0	1	0
102	68	12.8	0.4	14.8	11.0	1	0

AVERAGE AMP = 0.8 AVERAGE DIRECTION = 8.6

(Sheet 3 of 3)

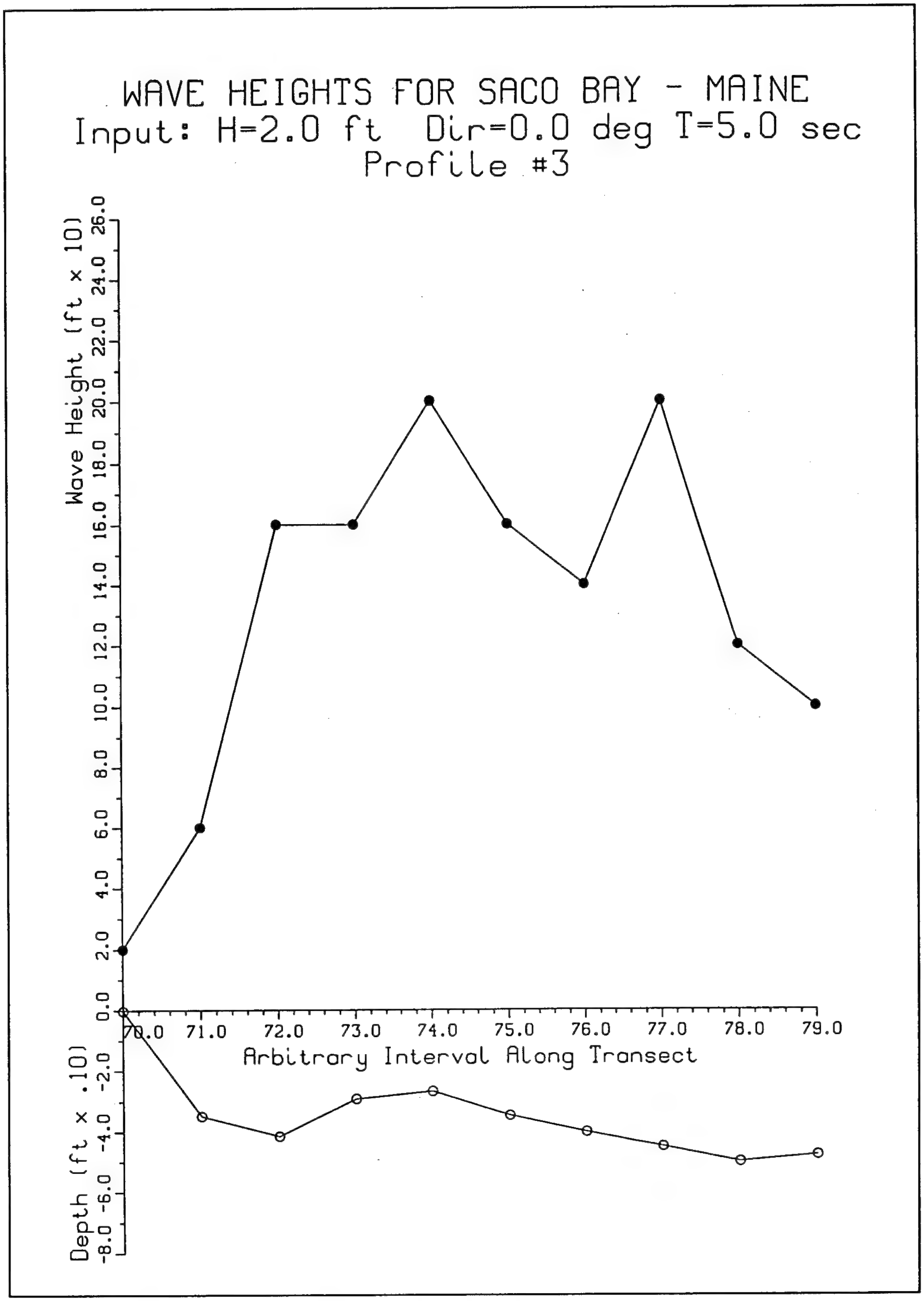


Figure A4. Example of line plot generated during the study

amplitudes at the wave generator location (TR 3) vary with incident wave direction and wave period. For some angles, wave amplitudes along TR 3 were less and for others they were substantially higher than amplitudes offshore. It was found that, for example, for 0-deg incident waves, the maximum wave amplification along TR 3 (i.e., the largest wave amplitude occurring on at least one of the 25 grid points for TR 3) occurred as follows: 10 percent for the 5-sec wave period (T), 30 percent for T = 7 sec, 90 percent for T = 9 sec, 40 percent for T = 11 sec, 0 percent for T = 13 sec, and 10 percent for T = 15 sec. The five transects close to the beach north of the north jetty (TR 1, TR 2, TR 5, TR 6, and TR 7) all appeared to experience equal or less amplification of the wave amplitude for this wave angle. The highest amplification (180 percent) along TR 3 occurred for -13-deg and -22.5-deg incident wave angles. Wave period also seemed to play an important role in the amplification of nearshore waves.

However, care should be exercised in interpretation of plots, particularly for the TR 3. For this transect, the 10 grid points nearest to the transect line among the 25 total grid points listed in tabular form have been selected for plotting. Consequently, the x-axis corresponds to grid points so chosen, and the spacing on the x-axis is the distance between these selected nodes, and not the distance along the transect. For five other transects, the x-axis represents the true grid distance. Combined wave height-water depth plots are useful to examine the spatial variation of wave amplitudes as waves propagate from one point to another. Since these line plots provide more direct information about wave height change than the contour plots covering the entire modeling area, they were used in the earlier phase of numerical study. As tabular output was preferred for the physical modeling study, plots were discontinued in the later phase.

The nearshore wave model REFDIF could not be calibrated or verified since no measured wave data of high quality were available over an extended period in the immediate vicinity of the Saco River jetties.

The 20-year WIS hindcast for Saco Bay was next applied to the Snell's law wave transformation using linear wave theory. Wave period and direction combinations with unit amplitudes were input into another computer program developed during this study to create corresponding arrays of amplitudes, periods, and directions for each point in the grid. Subject to the assumptions for Snell's law and linear wave theory, hindcast-based input wave data were transformed from deepwater to selected depths along six transects in Saco Bay.

Results from the application of Snell's law were presented only in tabular form similar to those for REFDIF model predictions. Additional information listed in tables for Snell's law output included shoaling and refraction coefficients. Deepwater incident wave parameters were designated by AMP0, DIR0, and PER0, while the computed wave parameters were designated DEP (local depth), AMP (local wave amplitude), PER (wave period), IBRK (wave breaking index), KS (shoaling coefficient), and KR (refraction coefficient).

Linear theory-based shoaling and refraction coefficients and REFDIF model predictions were all provided for the physical model study.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
August 1995

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Camp Ellis Beach, Saco Bay, Maine, Model Study of Beach Erosion; Coastal Model Investigation

5. FUNDING NUMBERS

6. AUTHOR(S)
Robert R. Bottin, Jr., Marvin G. Mize, Zeki Demirbilek

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
Coastal Engineering Research Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report
CERC-95-11

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Division, New England
424 Trapelo Road
Waltham, MA 02254-9149

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A 1:100-scale (undistorted) three-dimensional hydraulic model was used to investigate the effects of proposed modifications at Camp Ellis Beach, Saco Bay, ME, with regard to shoreline erosion at the site. The model reproduced about 2,438 m (8,000 ft) of the Maine shoreline, Camp Ellis Beach, the Saco River entrance, and sufficient offshore area in the Atlantic Ocean to permit generation of the required test waves. Proposed improvements consisted of roughening a portion of the existing Saco River north breakwater; installation of a sandfill, offshore berms, and spur jetties; and the removal of the existing north breakwater. Historical tests also were performed to aid in understanding formative processes at the site. A 24.4-m (80-ft-long) unidirectional, spectral wave generator, an automated data acquisition and control system, and a crushed coal tracer material were used in model operation. Test results led to the following conclusions:

a. During periods of storm wave activity and high tide conditions (+2.7 m (+8.8 ft)) at Camp Ellis Beach, wave heights ranging from 2.4 to 2.7 m (8 to 9 ft) will occur adjacent to the beach for existing conditions. For extreme storm events with tides in excess of +4.0 m (+13 ft), wave heights adjacent to the beach will reach approximately 3.4 m (11 ft). Little wave energy appears to reach the area, however, for low tide conditions (0.0 m or ft).

14. SUBJECT TERMS

Beach erosion	Hydraulic models
Breakwaters	Shoreline protection
Camp Ellis Beach, Saco Bay, Maine	Wave action

15. NUMBER OF PAGES
246

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

13. ABSTRACT (Concluded).

b. Sediment tracer tests for existing conditions indicated that erosion would occur along Camp Ellis Beach for the higher tide levels with net movement of sediment generally in a northerly direction. Larger wave conditions would result in an increased rate of erosion. For the lower tide levels, however, test waves would not move sediment out of the immediate area of Camp Ellis Beach.

c. The roughened breakwater plan (Plan 1) would not significantly reduce wave heights, alter current patterns and magnitudes, or prevent erosion in the vicinity of Camp Ellis Beach. Test results were very similar to those obtained for existing conditions.

d. For the beachfill plans with existing (Plan 2) and roughened (Plan 3) breakwaters, sediment would move north, and beachfills would eventually erode to the existing shoreline. The beachfill plans would only be temporary solutions to the erosion problems at Camp Ellis Beach (i.e., requiring periodic renourishment).

e. The 152,920-cu-m (200,000-cu-yd) Plan 4 submerged berm configuration initially would result in reduced wave energy reaching the beach and a slightly reduced rate of erosion along Camp Ellis Beach. The 76,460-cu-m (100,000-cu-yd) Plan 5 submerged berm configuration provided minimal wave protection and would initially result in erosion along the beach similar to existing conditions. Sediment from both berm configurations would migrate toward, and feed, the beach. After continued exposure to wave action, the berms would erode to a point where they provide little or no protection and sediment will migrate north; thus, the submerged berms would only be temporary solutions to the erosion problems at Camp Ellis Beach.

f. Of the spur plans tested, the +4.6-m (+15-ft) crest elevation, 914-m-long (3,000-ft-long) structure of Plan 7 was most effective in significantly reducing wave heights along Camp Ellis Beach. Both Plan 7 and the +4.6-m (+15-ft) crest elevation, 457-m-long (1,500-ft-long) structure of Plan 8 would be effective in preventing erosion of the beach. For both plans, sediment would remain in the immediate vicinity and not migrate in a northerly direction. The longer Plan 7 spur jetty would provide a more stable shoreline and protect a longer reach than the Plan 8 structure.

g. Removal of the north breakwater (Plan 9) would not significantly reduce wave heights, alter current patterns and magnitudes, or decrease the erosion rate along Camp Ellis Beach. Since the north breakwater's impact on hydrodynamics off Camp Ellis Beach is minimal, the presence of the structure should result in insignificant changes in the northerly migration of sediment along the beach. Breakwater removal would, however, significantly increase wave heights in the navigation channel. Test results also indicate that the 91-m^3/s (3,200-cfs) Saco River discharge would have no impact on the erosion rate along the beach.

h. Pre-breakwater conditions of 1866 indicated that the ebb shoal at the river mouth would meander, forming offshore bars and building the beach. These bars would severely hamper, if not stop, navigation. The original +3.0-m (+10-ft) el breakwater constructed in 1873 resulted in similar shoaling patterns, since sediment moved over and through the structure. The raised +4.6-m (+15-ft) el breakwater, completed in 1897, reduced navigation channel shoaling and resulted in offshore bar formations north of the structure and seaward of Camp Ellis Beach. All conditions tested with the historical alternatives resulted in sediment constantly moving north out of the Camp Ellis Beach area, thus suggesting eventual erosion without nourishment or replenishment of the beach.